

**CORDILLERA REAL
GEOLOGICAL RESEARCH PROJECT**

**THIRD ANNUAL REPORT
(APRIL 1988 – MARCH 1989)**



British Geological Survey

**Keyworth
Nottinghamshire**

PATRI MATRIQUE



Project field party negotiating the Río Parcayacu tributary along the Río Mulatos traverse

Divine intervention?

Yes, they'd warned me about Gallo Urco:
Five days down the river, they said.
You have to clamber an enormous cliff,
Instead of going on ahead.

'It's a rocky cliff with forest up high,
Around three thousand feet in height.
And it takes all day to get to the top,
Where you are forced to pass the night.'

'You must clamber down the very next day,
Back down to the river again.
Gallo Urco's the point of no return.
Between success or all in vain.'

I'm climbing it now! My pack is heavy!
Just holding to tussocks of grass.
Whilst well down below, with white water spume,
The Mulatos roars through the pass.

My legs are gone! I can't climb anymore!
And the boys are well out of sight.
I can't go back down, I will fall and die!
Shivering in a rain-soaked fright.

Is this the end? Can nobody hear me?
Over the river's mighty roar.
I cannot go up; I cannot go down:
Stuck to this rock for evermore.

I face the rock cliff, so dank, dark and wet,
Then 'HELP ME!' rings out like a shock.
A single cry to the God of the heart,
Striking my head upon the rock.

Now! I feel charged as if to a socket!
And gasping the mist through the throat,
Up the mountain propelled like a rocket,
Flying just like a mountain goat!

I pass Ramiro and the one-armed man,
Even time to hammer some rocks.
So we make our camp in the pouring rain,
Trying to dry those bright red socks.

These sips of single malt take me away,
Out of the body's earth-tied bed.
So was it really my Damascus Road?
I'll only find out when I'm dead.

Martin Litherland

Inca Treasure

Poems from the Andes of Ecuador



A camp by the Rio Mulatos. The clothes are drying on the rocks and the fire is lit.
Because we are on the Equator it gets dark around 6.00 pm every day



Enormous skarn boulder in the Río El Placer derived from the El Placer skarnfield

Overseas Development Administration,
Foreign and Commonwealth Office,
United Kingdom of Great Britain
and Northern Ireland

Ministerio de Energía y Minas,
República del Ecuador

CORDILLERA REAL
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(APRIL 1988 – MARCH 1989)

compiled by

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Gracias a todos quienes ayudaron en el rescate del Ing. Francisco Viteri, cuando la Parca conspiraba contra él, durante una travesía de Jimbilla hasta Quimi, abril 1989.

“Más era necesario hacer fiesta y regocijarnos, porque éste tu hermano era muerto y ha revivido; se había perdido y es hallado”.

San Lucas 15,32 (Versión Antigua)

Thanks to all who helped in the rescue of Ing. Francisco Viteri when the Fates conspired against him, on a traverse from Jimbilla to Quimi, April, 1989

“But it was meet to make merry and be glad: for this thy brother was dead, and is alive again; and was lost and is found”

St. Luke 15,32 (Revised Version)

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ABSTRACT

This report accounts for the work undertaken from April 1988 to March 1989 under the Cordillera Real Geological Research Project: a bilateral (ODA-INEMIN) Technical Cooperation programme. It includes and summarises the results of geological field work, chemical and mineral analyses and petrographic, palaeontological and geochronological (K-Ar) studies undertaken during this period.

Geological fieldwork has concentrated on two main sectors of the Cordillera Real: in the north the metamorphic complex between the Salado and Cosanga rivers; and in the south the metamorphic complex between the Río Paute and the Peruvian border. Geological maps on the scale of 1:250000 are included for these sectors, along with larger-scale geotraverse maps.

The work programme has further defined the geology and mineral potential of the cordillera. In the north the “collision” scenario now involves the main (Peltetec) ophiolitic suture followed eastwards by the Maguazo/Alao-Paute island arc (with Oxfordian- Callovian palynomorphs); followed east across the Baños front by the Tres Lagunas (?collision) granites and then by a major nappe sequence which can be divided into a tectonic stratigraphy essentially based on continent-derived metasediments, skarns and serpentinites thrust over the Azafrán island arc plutonic/volcano-sedimentary pair. These in turn are thrust, along the sub-Andean front, over a “cratonic” Jurassic continental arc pair manifested as the Abitagua granite and Misahuallí volcanics. The sub-Andean zone also exhibits Tertiary thrusting of Cretaceous units; presumably the rejuvenation of collisional thrusts of the Jurassic orogeny.

To the south the Azafrán island arc dies out and the Cordillera Real is dominated by major developments of the Tres Lagunas metagranite and continental semipelites, thrust, along the sub-Andean front, over the higher-grade rocks of Sabanilla, which are in turn thrust over the “cratonic” Jurassic continental arc complex of the Zamora batholith. Later Cenozoic volcanic/subvolcanic activity is particularly prominent in the southern zone.

Regarding mineral potential, new mineral indications, both metallic and non-metallic, and geochemical anomalies are noted from the geotraverses. In the south, special studies have been made of the gold/polymetallic mineralisation.

In this report mineralisation is linked to basement units or structures, despite the observation that many of the important prospects relate to younger Cenozoic intrusives. Thus, in the west the polymetallic belt is hosted by the Alao-Paute island arc up to the Baños front which is a major gold belt. Further east the Nambija mines are part of a regional gold belt geographically related to the Zamora volcanic-plutonic complex. Mineralisation varies in type from epithermal skarn-hosted to epithermal sub-volcanic; the age of the latter may be Cenozoic. Tin-tungsten deposits close to the Baños front are also of probable Cenozoic age, but may relate genetically to the Tres Lagunas granite basement.

In the north, the Llanganates skarn belt has been traced for 150 km in the form of skarnfield klippen; molybdenite mineralisation was noted. It is thought that both the skarn and the source of local gold placers relate to the Azafrán island arc volcano-plutonic complex.

1. INTRODUCTION

1.1 Nature of this report

This is the third of a series of open file annual reports on the Cordillera Real Geological Research Project: a bilateral Technical Cooperation project between the Governments of Ecuador (Instituto Ecuatoriano de Minería-INEMIN: Ministry of Energy and Mines) and the Government of the United Kingdom of Great Britain and Northern Ireland (Overseas Development Administration-ODA), which began in March, 1986. The ODA Technical Cooperation officers are recruited from the British Geological Survey (BGS). The present report covers the period April 1988-March 1989.

The project aims to study the metamorphic rocks of the Cordillera Real of Ecuador. Its objectives are the elucidation of their nature, structure, relationship and mineralisation in order to discover the patterns of metallogenesis and provide the scientific base for estimating their mineral potential, and thus a database to promote the Ecuadorian Mining Industry.

For details of background, topography, drainage, climate, vegetation, population, access, topographic maps, imagery, previous geological work and mining history, the reader is referred to the first annual report (Litherland, 1987).

1.2 Personnel

For the third year the Project continued with the following ODA residential staff seconded from BGS:

Dr. Martin Litherland (Project Leader)
Dr. John Aspden

The following INEMIN personnel were assigned to the project:

Ing. Francisco Viteri Santamaría (Counterpart Project Leader)
Ing. Miguel Pozo Torres
Lcda. Fabiola Alcocer Carrasco (Mission secretary)
Sr. Manuel Célleri Ortiz (Field assistant)

1.3 The April 1988-March 1989 work programme

1.3.1 Reconnaissance field programme

In the north of the Cordillera Real the following geotraverses were undertaken (Figure 1, Map 1):

- (a) Cangahua-Oyacachi-El Chaco (Litherland and Pozo).
- (b) Laguna Micacocha-Cosanga (Litherland and Pozo).
- (c) Río Azuela (Litherland and Pozo). They failed to complete traverse down Río Salado due to earthquake damage and thus undertook the following traverses:
- (d) Río Salado-Río Diviso (Litherland) upstream for Salado Pumping Station.
- (e) Cayambe town-Sara Urco (Pozo).

The following geotraverses were undertaken in the south of the Cordillera Real (Figure 1, Map 8):

- (a) Amaluza-Loma de Arenal-Palanda (Viteri)
- (b) Jimbura-San Andrés-La Diversión (Aspden)
- (c) Yangana-La Canela-Río Vergel (Aspden and Viteri)
- (d) Pico Toledo-Numbala Alto (Viteri)
- (e) Nabón-Espíritu Playa (Viteri)
- (f) Cochapata-San Vicente-Veintiocho de Mayo (Aspden)

1.3.2 Follow-up field programme

- (a) Ing. Pozo made a detailed study of the Tampanchi mafic/ultramafic igneous complex.
- (b) Dr. M. G. C. Clarke (short term ODA Economic Geologist) and Ing. Viteri carried out follow-up studies on the mineral belts of the southern Cordillera Real (see Appendices 3, 4, 5 and 6).

1.3.3 Geochronology

The K-Ar results from the first Project geochronological programme are presented as Appendix 8.

The second geochronological programme began in the new year. Dr. S. Harrison (short term ODA geochronologist), accompanied by Dr. Aspden and Ing. Viteri, collected samples for the K-Ar, Rb-Sr and Sm-Nd methods from new sites in the Cordillera Real and El Oro metamorphic province, as well as recollecting from certain sites of the first programme where results were unsatisfactory.

1.3.4 Petrographic and mineral studies

Project team members have continued petrographic studies of samples collected from the geotraverses.

Specialized petrographic and mineral studies have been undertaken at BGS (see Appendices 4, 5, 6 and 7).

1.3.5 Chemical analysis

Routine trace element analysis of stream sediments and rocks have been carried out at the INEMIN laboratories, Quito (Appendices 1 and 2).

BP Minerals have sponsored the analysis of various rock samples at ACME Laboratories, Vancouver (Appendix 1).

In UK, ore analysis has been carried out at Caleb Brett laboratory (Appendix 4), and gold analysis in the BGS laboratory, Edinburgh (Appendix 6).

1.3.6 Palaeontological studies

Nine palaeontological reports, involving the Biostratigraphy Research Group (BGS) and Nottingham University, are enclosed as Appendix 9. These include studies on palynomorphs, ammonites, conodonts and molluscs from the Cordillera Real and environs of Ecuador.

1.3.7 Commissions reports and maps

Reports compiled for INEMIN following field commissions are presented in Appendix 10. Commission maps are presented in a separate binder.

1.4 Report and map presentation

Again, this annual report attempts to include the data obtained by the Project in the period in question so as to be of maximum benefit to interested parties. The summary is produced in Spanish and English versions, but the Appendices appear in their language of presentation.

The summary of the geology has been made with the benefit of information from microscopic thin sections. It therefore supersedes descriptions presented in the field reports (Appendix 10) and field commission maps.

Time is shorter this year to produce this annual report. Thus, the summary is shorter; however, the detail in the chapters on economic geology has been maintained.

Maps are presented in a separate binder in an ordered sequence covering the two main areas of study. The 1:250000 scale compilations are drawn on a topographic base prepared by the Project team from existing surveyed IGM sheets and LANDSAT information.

1.5 Acknowledgements

We are again indebted for financial and administrative support to INEMIN through the ex-Gerente General, Ing. Guillermo Bixby G., subsequently Ing. Leonardo Elizalde C.; and to ODA through both the Ecuadorian Desk Officer, Mr. Robin Russell, and Mr. Redmond Norton, subsequently Mr. Douglas de Wilton, Aid Officer, British Embassy, Quito. Mr. Russell's ability to find money for the additional programmes of Dr. Clarke and Dr. Harrison is deeply appreciated.

We also appreciate the scientific support provided by the ex-Gerente Técnico of INEMIN Ing. Edgar Salazar, subsequently Ing. Wilson Santamaría, and Dr. C. R. Jones, subsequently Dr. J. D. Bennett, BGS Regional Geologist, Latin America and Asia.

It is also a pleasure once again to note the contribution to this report made by BP Minerals International.

"Friends of the Project", in both the Ecuador public and private sectors have helped the project team and this report with useful exchanges of information. We hope that we can continue working together for the benefit of Ecuadorian geology and the Ecuadorian Mining Industry.

2. GEOLOGY

2.1 Introduction

The tripartite division of the Cordillera Real metamorphic and plutonic rocks used in the previous annual reports is maintained as follows (Figure 1):

- (a) The Western Belt: limited to the east by the Baños front.
- (b) The Central Belt: limited to the west by the Baños front and to the east by the sub-Andean front.
- (c) The Eastern (sub-Andean) Belt: limited to the west by sub-Andean front and to the east by the western limit of the Amazonic craton.

The following summary represents the annual “update” on these three belts and their respective geological elements and histories.

2.2 The Western Belt

2.2.1 Introduction

The major outcrop area is north of Cuenca (Figure 1) where the main divisions of the Western belt were mapped in the first two years of the Project (Litherland, 1987; 1988). The present update is based on the limited field and sample studies undertaken during the period in question.

2.2.2 The Guasuntos, Guamote, Cebadas, Peltetec and Maguazo divisions

Little further data has been collected on these units. There are some chemical analyses of ophiolitic rocks from the Peltetec division of Penipe, Peltetec and Huarguallá as part of a nationwide analytical survey of ultramafic-mafic complexes (Appendix 1, Table 1). Palaeontological data from the Maguazo division is given in 2.2.5.

2.2.3 The Alao-Paute division

On Map 8 the rocks to the east of the Maguazo division are shown as belonging to the Alao-Paute division. It should be noted, however that it may become necessary to sub-divide this sequence. In the west, generally massive, weakly metamorphosed andesites and agglomerates predominate, whilst in the east these are replaced by a mixed sequence of schists and phyllites, mylonitic in places. The rocks are volcano-sedimentary in origin and include, as well as greenschists and more massive greenstones, graphitic phyllites and felspathic phyllites, together with minor quartzites ($\pm$ chloritoid) and black marbles. The principal metamorphic minerals are chlorite, epidote, zoisite, clinozoisite, and tremolite/actinolite. In some instances, original plagioclase phenocrysts are preserved in the greenschists and thin section evidence indicates that these rocks most probably represent lavas which have been cataclastically deformed and dynamically metamorphosed.

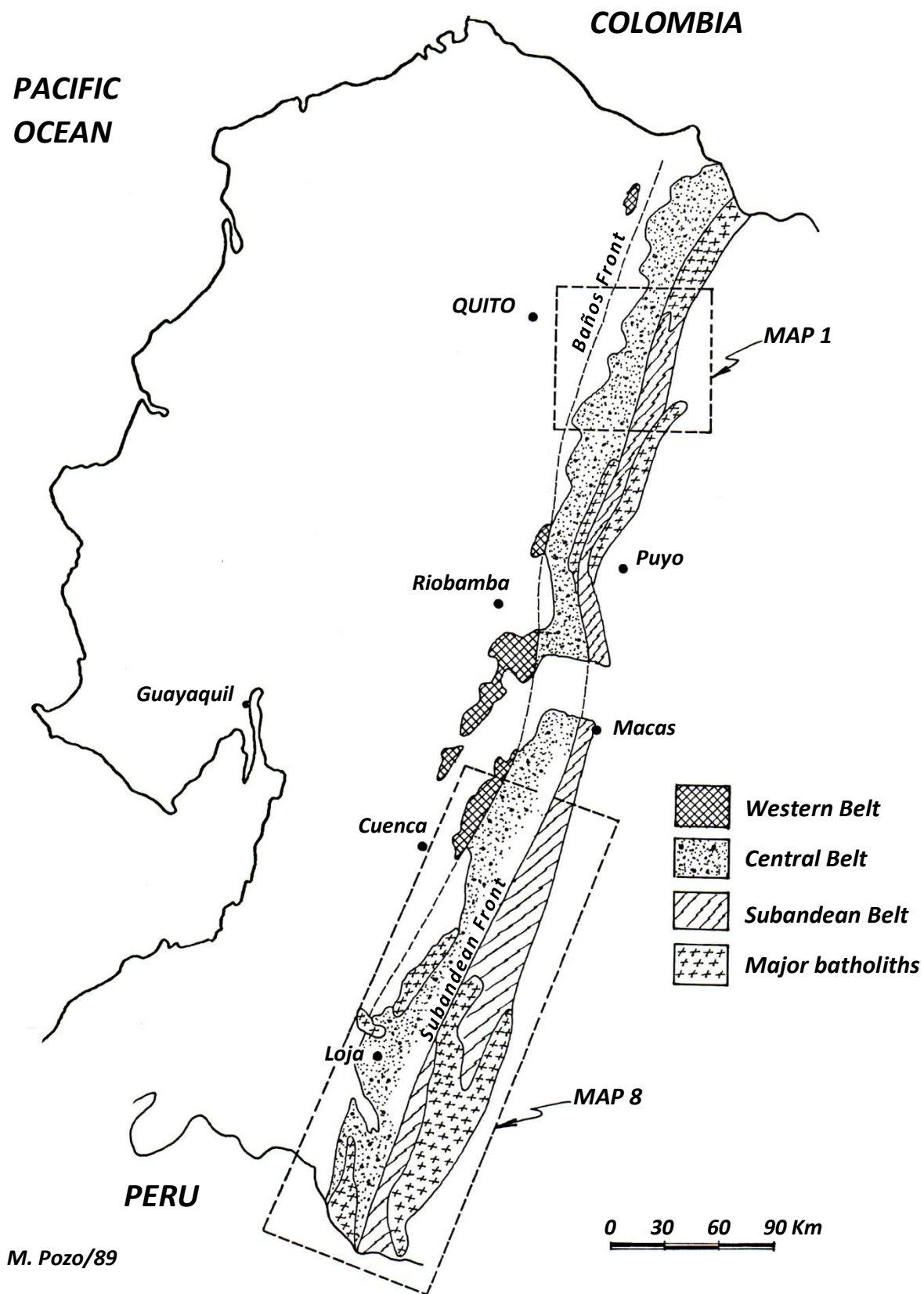


Figure 1. Tectonic subdivisions and major batholiths of the Cordillera Real. 1988-1989 Project work areas are indicated.

In general terms these rocks correspond to the El Pan schists of Bristow and Guevara (1980) and regionally their western limit probably coincides with an approximately N-S zone of faulting (shearing) that can be traced on the airphotographs immediately to the west of the Río Paute and which continues northwards towards Laguna Aucacocha (Map 8). This zone also defines the eastern edge of the fault-bounded Tampanchi mafic/ultramafic complex and in general corresponds to the eastern limit of the more massive meta-andesite sequence of the Alao-Paute division.

In the absence of age determinations, the meta-andesites in the west and the metavolcano-sedimentary rock to the east are considered to be contemporaneous, the latter possibly represents a backarc sequence. However, the possibility that these units are unrelated and of different ages cannot at present be ruled out.

Small outcrops of mylonitic greenschists and green phyllites were located further south: east of Nabón, west of Saraguro, and near to Quilanga along the Las Aradas fault (Map 8). Mineralogically and tectonically these rocks are very similar to the mylonitised Alao-Paute meta-andesites which occur to the south of Sigsig along the Baños front. Their presence is of regional significance since it indicates that the Alao-Paute volcanism probably extended southwards into northern Peru. The existence of these rocks, together with the Loja division and the Tres Lagunas suite, along the Las Aradas fault, strongly suggests that this structure represents the southern continuation of the Baños front.

2.2.4 The Tampanchi mafic-ultramafic complex: an Alaskan pipe?

Further studies on this elongate complex (Map 2) indicate that the body could be interpreted as a series of shells with an ultramafic core and mafic margin. Thus serpentinites/ultramafic rocks may be followed outwards by shells of clinopyroxenite, hornblende and gabbro, pegmatitic in places. This shell-configuration resembles that of Alaskan-type ultramafic pipes (Taylor, 1967) both in form and in compositional types. Some features at Tampanchi, e.g. the absence of both orthopyroxene and well-defined igneous layering, also resemble the Alaskan pipe model.

Such pipes have since been identified in the Urals, Venezuela (Murray, 1972), British Columbia and New South Wales (Australia) (Anon, 1988), and it seems that many former “ultramafic complexes” can be interpreted in this fashion rather than as Alpine ophiolites.

Alaskan pipes are believed to occur over zones of long-standing subduction and may relate to andesite feeders at depth (Hughes, 1982). It must be stressed, however, that such an interpretation for Tampanchi is provisional.

2.2.5 New ages from the Western belt

- (a) Float samples from the Río Jadan of Maguazo division calcareous black phyllite with chert have yielded palynomorphs of Callovian-Oxfordian stages (Appendix 9, Report WH/88/347R). This is of ca. 156-169 Ma, or Middle to Late Jurassic age, and represents a very important age determination for Ecuadorian geology. It finally rules out any correlation between the non-metamorphic Yunguilla (Maastrichtian) Formation of the Cuenca area and rocks of the metamorphic complex, as suggested by Bristow et al. (1975), although field evidence alone is sufficient to deny it (Litherland, 1988, p. 13).
- (b) Attempts were made to date the meta-andesites of the Alao-Paute division by the K-Ar method, but the ages obtained (100 ± 8 Ma and 142 ± 36 Ma) are considered to be unreliable (see Appendix 8), since the samples were partially altered and the separated minerals had low potassium contents.
- (c) Late, undeformed plutons of the Western belt “basement” were also dated in the K-Ar programme. The Magtayán pluton (Litherland, 1988, Map 1) gave an age of 75-80 Ma similar to the hornblende K-Ar dates of 75 Ma and 85 Ma reported in Kennerley (1980). The Pungalá pluton (Litherland, 1988, Map 1) gave an Eocene age of 43 ± 2 Ma.

2.3 The Central and Eastern Belts

2.3.1 Introduction

The work undertaken by the two project field teams in the north and south of the cordillera has confirmed the presence of certain regional Andean-trending lithological divisions as well as establishing a tectonic stratigraphy over an area of nappe tectonics southeast of Quito. This section attempts to summarise this new local and regional information.

2.3.2 The Tres Lagunas granite suite and associated rocks of the Central Belt

This unit of granite and metagranite (orthogneiss), in places characterized by the presence of blue quartz, has now been traced from Oyacachi in the north (Map 1) to the Peruvian border in the south (Map 8), and thus represents an important new component in the geology of the Cordillera Real. It invariably crops out immediately east of the Baños front and only appears to be altogether absent north of Oyacachi and west of Macas; narrow tectonics slices are found in the Peltetec ophiolitic mélange division of the Western belt (Litherland, 1988).

Apart from Project field and microscopic studies, there are petrographic reports by Atherton (Litherland, 1988, Appendix 6), and Danger- field (this report, Appendices 5 and 7). There are also whole rock analyses and a preliminary interpretation by Clarke (Appendix 6).

The regional distribution of the Tres Lagunas suite in the south is shown on Map 8. Although exposure is relatively poor and much of the western margin of the cordillera is covered by the apparently undeformed Palaeocene deposits of the Sacapalca Formation (Baldock, 1982) the western limit of the suite coincides with the Las Aradas Fault zone which is now considered to represent the southern extension of the Baños Front.

Detailed field mapping will be required to establish the precise boundaries of the various granite bodies, but it is probable that the principal contacts are tectonic. The presence of the unit in the Río Airo, to the north of Amaluza, and in the Río Elvira, to the east of Quilanga, is based solely on the occurrence of float blocks, but it is probable that extensive outcrops exist in this general area of the cordillera.

To the east of Ona (Map 14), the northward extension of the suite from the Tres Lagunas area has been confirmed, and appears to form a coherent, continuously exposed, albeit deformed and probably detached intrusive body which is now referred to as the Tres Lagunas batholith: an important new plutonic body on the geological map of Ecuador.

The southern limit of the batholith, i.e. in the area around Laguna Grande, remains to be field checked but in the north, in spite of the fact that to the east of Gima it is largely covered by young volcanic deposits of the Tarqui Formation, it probably extends into the area of the Río Santa Bárbara to the south of Sigsig.

Based on hand specimen identification and thin section information the granite is compositionally restricted and probably ranges from monzogranite to granodiorite. The more massive parts are typically medium- to coarse-grained and in places carry megacrysts of blue-grey alkali feldspar in which Carlsbad twins may be visible. Hornblende is absent and the major mafic phase is biotite, which in thin section is typically foxy-red in colour and may contain symmetrical arranged rutile needles. The biotite is relatively coarse (up to 1 cm across) and generally forms 10% of the mode. It occurs either in books or in clots, which, on freshly broken surfaces, give the rock a rather characteristic spotted appearance. In addition, many samples contain brightly coloured blue quartz; the origin of this colouration is uncertain, but most probably it is related to microshears which affect the optical characteristic of individual crystals.

On cut surfaces it can be seen that the alkali feldspar megacrysts normally contain inclusions of pale, cream-coloured plagioclase and/or biotite $\pm$ quartz. Narrow rims of blue-grey alkali feldspar have been observed surrounding earlier-formed subhedral plagioclase crystals; “rapakivi type” textures, i.e. alkali feldspar with plagioclase rims, have also been noted. The plagioclase, where determined, is normally in the albite-oligoclase range, whilst the alkali feldspar includes orthoclase, microperthite, microcline and microcline-microperthite.

Garnet may be present and, more rarely, cordierite. Muscovite is fairly common but, in most cases, it is subordinate to biotite which it may replace. It also occurs as an alteration product (sericite) after feldspar. Zoisite and chlorite are normally present as are trace amounts of apatite and opaques.

In some areas, e.g. near to Tres Lagunas to the east of Saraguro, disseminated pyrite is relatively common. Tourmaline, which is often demonstrably late, is also widely distributed. To the SE of Gima, near to Moriré, a foliated, pale-green muscovite-tourmaline-bearing variant occurs (see Appendix 1, sample CR/FV/359), and 2-mica granites, “greisens”, which are assumed to belong to the suite, have been reported to the east of Saraguro in the upper reaches of the Río Casaturo (Río Pichanal in Map 8) (UNDP, 1972; Misión Minera de España, 1977). Minor amounts of “greisen type” alteration is also present in the Loma del Inca to the east of Las Aradas and to the NW of Loja where it is associated with late pegmatitic, crosscutting, quartz-feldspar $\pm$ muscovite $\pm$ tourmaline veins. Xenoliths are relatively rare, but greenschists, of metavolcanic/volcanoclastic origin, quartzites and “aplitic” variants of similar composition to the host, have been observed. Xenocrysts of quartz, which may reach several centimetres in size, are present and are especially common in the body which is exposed to the west of Vilcabamba along the west margin of the Malacatos Basin.

Although away from shear zones substantial areas of relatively massive rocks which still preserve many of the original plutonic characteristics do exist, the bulk of the granites in the south are strongly sheared and typically gneissic in appearance. As a general rule these gneisses are Andean-trending with moderate to steep foliation-dips. However, it should be noted that areas which show relatively flat dips (i.e. 30°) are also present. To the north of Tutupali (Map 8) trans-cordillera strikes have been recorded along the eastern margin of the Tres Lagunas batholith.

The most intensely deformed areas have been observed near to the Baños front in the west, but it is now clear that the entire suite has been affected. Shear zones (?thrusts), although variably developed, are present throughout the main Tres Lagunas batholith. It is assumed (though not proven) that in the east the Tres Lagunas batholith was intruded originally into the semi-pelitic rocks of the Loja division. However, it is considered most probable that all the main contacts are now tectonic and certainly the smaller bodies, for example in the Sigsig-Principal-Río Collay area, are interpreted to be detached, fault-bounded lenses (Map 8).

Field observations and thin section evidence indicate that, at the present levels of exposure, cataclastic processes played an important role in the deformation history, and as such these events may considerably post-date the emplacement of the plutonic complex. The most common rock types seen consist of foliated granite, megacrystic in places; biotite gneiss and augen gneiss, which may contain augens up to four centimetres across of blue-grey alkali feldspar $\pm$ quartz. With increasing deformation, i.e. proximity to a major shear zone, the igneous nature of the protolith is progressively destroyed. In particular, the grain size is mechanically reduced by an increase in the abundance of millimetre-scale, diastomising microshears, and the typical product of this process is a relatively fine-grained, pale-coloured, micro-augen schistose rock.

Based on a collection of 16 samples, Dangerfield tentatively suggested that a sequence of mineralogical transformation and textural modifications related to “progressive cataclastic metamorphism” could be recognized in thin section, and these are detailed in Appendix 7.

A number of late-stage phenomena have been observed:

- (a) The development of tourmaline veins and veinlets.
- (b) The development of quartz-feldspar-muscovite-tourmaline pegmatite veins.
- (c) The development of quartz veins, sheets and balls, some of which carry pegmatitic tourmaline.

In most cases these events are demonstrably late, since they cut the main foliation, but it is possible that they reflect late-stage processes rather than a separate and entirely younger event.

North of the Tres Lagunas type area, the granite is found intermittently close to the Baños front (Map 8) except across the Río Paute and Guamote-Macas sections. The granite reappears on the Alao-Huamboya (Palora) traverse (Litherland, 1987).

North of Baños (Río Pastaza) as far as Oyacachi, granites, metagranites and augen gneisses, mylonitic and schistose in places, with or without the blue quartz “fingerprint”, are found almost entirely within a generally steeply-dipping belt along the west of the Central belt (Map 1). Associated rocks within this mappable belt include paragneisses, chloritoid-garnet-muscovite-schists, graphitic schists, amphibolites and quartzites, garnetiferous in places. Some of these lithological elements have been noted north of Oyacachi in the extreme west of the Río Azuela and Sara Urco traverses.

A belt of “granoblastic” (granofelsic) quartz-garnet-?feldspar rocks can be traced from Oyacachi to Papallacta (Map 1) within this Tres Lagunas metagranite domain. They are characterized by pink-violet garnets up to 1 cm across and blue-grey quartz. The percentage of sericitic masses after ?feldspar is insufficient for a granitoid protolith and could, alternately, represent the alteration of an alumino-silicate (?kyanite). In the Río Chalpi de Papallacta there are blocks of this lithology alongside blocks of migmatitic semi- pelitic paragneiss indicating that this belt contains medium- to high-grade rocks (i.e. the rocks were beginning to melt).

With regard to the origin of the Tres lagunas suite, the narrow compositional range, the presence of muscovite and absence of hornblende, and the occurrence of garnet and cordierite all suggest the presence of S-type granites, derived from the continental crust and interpreted by many to reflect crustal melting generated from continent-continent collision. The chemical analyses and variation diagrams presented by Clarke in Appendix 4 tend to support the S-type interpretation. The increase in metamorphic grade of the host rocks from south to north probably reflects a lowering of crustal level so that the Oyacachi-Papallacta rocks were formed closer to the zone of melting.

2.3.3 Metasedimentary and metavolcanic rocks of the Central Belt

The Central belt of the Cordillera Real is dominated in the south by the Tres Lagunas granitic suite and the low-grade semi-pelitic sequence of the Loja division (Litherland, 1987; 1988). North of the Gualaceo-Limón road, however, metavolcanic and schistose metasedimentary units are also present and their relation with the Loja division are still undecided. However, one significant result of the northern studies was the recognition of a “Loja-type” semipelitic quartzite/black phyllite unit as part of the nappe sequence.

Details on the geology of the Loja division in the south are found in Litherland (1988). Additional information can be summarized as follows:

- (1) It has now been confirmed that phyllites $\pm$ graphite and quartzites of the Loja division are present in the western part of the Cordillera Real to the south of Quilanga (Map 8) and that their western limit corresponds to the Las Aradas fault. It is probable that these rocks extend into Peru but based on the evidence of xenoliths which were found near the Peruvian frontier in the Portachuela batholith it seems that the Loja division “thins” to the south and that there is a corresponding increase in the width of the Sabanilla division.
- (2) Although the Loja division metasediments are generally of low metamorphic grade, garnet may be locally developed. Along the Gualaceo-Limón road, immediately to the east of the main watershed, a flat-lying sequence of strongly-cleaved, quartz-rich “schistose” rocks occurs in which garnet is sometimes present. According to Trouw (1976, p. 21), this mineral, together with biotite, dies out further to the east. Garnet also occurs in a small euhedral crystal in similar quartz-rich schistose rocks which outcrop in the headwaters of the Río Tres Lagunas to the east of Guel (Map 8).

As pointed out in (Litherland, 1988), to the north of the Gualaceo- Limón road there is an important lithological change in the cordillera across which the essentially non-volcanic metasediments of the Loja division are replaced along strike by a variable sequence of greenschists. Although phyllites and quartzites are still present they form only a relatively minor component of this sequence which is considered to be principally volcano-sedimentary in origin. The exact nature of this change remains uncertain and more detailed mapping will be required in order to solve this problem. For the time being, however, the greenschist are shown as representing a lateral facies variation in the Loja division on Map 8.

Moving north, the Guamote-Macas sector of the Central belt is dominated by metasediments and metavolcanics. Further north, over the 1988-1989 work area, the metasedimentary and metavolcanic rocks of the Central belt (Map 1), east of the steep Tres Lagunas belt, were observed to correspond to a tectonic stratigraphy with a subhorizontal foliation (Table 1). Map 1 shows a geological interpretation of the area between the Oyacachi and Cosanga rivers based on the traverse data. Geological contacts are traced from one geotraverse to another taking into account the regional tectonic dip and topography; there is no photogeological aid.

2.3.4 The Sabanilla (?Precambrian) and Masaca divisions

The Sabanilla division is a compound unit comprising medium- to high-grade metamorphic rocks (Litherland, 1988). It occurs as a tectonic wedge in the sub-Andean zone in the south of the cordillera (Map 8). It consists principally of foliated, possibly syntectonic, metaplutonic rocks but also includes metasediments which variously contain garnet, staurolite, sillimanite and kyanite. Hornblende amphibolites $\pm$ biotite are also relatively common especially within the metaplutons but the general form of these suggests that they were originally basic dikes or sheets. Preliminary thin section evidence shows that although the metaplutons are commonly partially re-crystallised they range from granodiorite to possibly tonalite in compositions. Biotite $\pm$ subordinate muscovite is invariably present, but hornblende is apparently absent.

Megascopically the plutons have a variable, but generally well-developed foliation. They are often inhomogeneous in appearance and, in particular, this is due to the presence of numerous biotite ($\pm$ muscovite) schlieren and/or the presence of partially digested xenoliths.

Gneissic xenoliths are especially common and, in some outcrops, it can be seen that the progressive digestion of this material produces the biotite-rich schlieren which are themselves then “streaked-out” and dispersed into the main body of the intrusive host. Late stage phenomena include the presence of undeformed veins and lenses of muscovite and/or biotite, quartz-feldspar pegmatites, and also of small, cross-cutting, tourmaline-bearing granite apophyses.

In some areas, e.g. to the north of Valladolid and in places along the Loja-Zamora road (see also Trouw, 1976), migmatitic rocks have been observed. It appears however, that such rocks are not developed regionally and it may be that they are essentially confined to contact zones of metaplutons rather than related to high grade metamorphism.

The Sabanilla mineralogy indicate a relatively deep crustal level, and it is possible that the division represents a Precambrian basement block upthrust along the sub-Andean belt, rather than higher grade equivalents of other lithological divisions of the cordillera.

The Masaca division named after a small village which is located to the north of Loja along the old road which leads to San Lucas (Map 8). Although similar to the Loja division, to which it may be related, the Masaca division consists principally of quartz-rich biotite schist which also contains minor amounts of muscovite, plagioclase and alkali feldspar. As shown at present this division also includes minor amounts of greenschists which are exposed in a quarry at the northern end of the Loja basin along the road which leads to Masaca. Structural dips are steep to vertical and strikes are NNE-SSW. Where seen, contacts with the Loja division are faulted.

Table 1. The Central Belt tectonic stratigraphy over the flat belt between the Ríos Oyacachi and Cosanga (thickness are tectonic not stratigraphic)

TOP:	Probably the Tres lagunas packet (see 2.3.2); this is not exposed over the flat belt, but further west in the Tres Lagunas steep belt. Llanganates skarns (see 2.3.5): ca. 200 m thick; crop out as high-level synformal klippen. Mixed schists: muscovite-chlorite schists, graphitic schists and thin quartzites, ca. 400 m thick, intercalated with Tres Lagunas-type metagranites along Papallacta river. Serpentine: thin Urcucocha belt east of Antisana, blocks probably from this level; some blocks of tremolite rock. Semipelites: banded and laminated, white fine-grained quartzites and black phyllite, typical of Loja division in the south, ca. 1200 m thick and with visible D2 folds with flat axial planes. Marble/dolomite: thin marker band of siliceous dolomite with rusty weathering in Río Cosanga; black marble in Río Oyacachi; dolomitic blocks have been noted in Río Quijos. Graphitic schist: prominent in Oyacachi-Quijos sector. Pelitic schist: thicker in northern Oyacachi-Quijos sector; typical assemblage contains muscovite with or without chloritoid and garnet.
BASE:	Greenstones: probably of andesitic affinity, intercalated with black phyllites and metagreywackes.

2.3.5 Skarn rocks, calc-silicates and marbles of the Central Belt

Skarn rocks of the Llanganates belt were first recognized in 1986 and the first skarnfield was discovered in the Llanganates in 1987. The petrology of this calcic magnetite skarn suite is detailed in Litherland (1987, Appendix 5) and Litherland (1988, Appendix 5). Field characteristics of these rocks include their multicolour nature: pink (garnet)-green (epidote)-black (amphibole-magnetite), and their massive appearance with “elephant skin” weathering.

The 1988-1989 studies further north have indicated the presence of the Llanganates skarn belt over the following sectors from south to north (see Map 1):

- (a) A new skarnfield (the Urcucocha field) was located in outcrop on the Antisana-Cosanga traverse (Map 3). The unit forms a small N-trending *serranía* about 200 m high and about 4000 m above MSL. Four main individual units can be mapped in the form of a gentle synform of the second tectonic foliation (S₂); there are also some very thin slices of Tres Lagunas granite. From the base the first (ca. 150 m) and third (ca. 50 m) units are massive to gneissose “skarn” rocks, in this case, comprising green epidotic rocks with epidote as medium-grained granular to equigranular crystals up to 90% in mode with lesser quartz, carbonate, chlorite and amphibole (pale blue-green). Protolith amphibolitic greenstones with calcite veins can be seen in one outcrop showing variable epidotization and the whole deformed and brecciated by the main (sub-horizontal) foliation. The second (80 m) and fourth (50 m) units are also similar (? repeated) units of a fine-grained quartz-muscovite-biotite-schist (not quartzite as shown on Map 3). Larger original feldspar crystals indicate a possible volcanic or volcanoclastic proto- lith. Recumbent folds were noted within the second unit. The Urcucocha field is interpreted as another high-level klippe of the Llanganates skarn belt.
- (b) In the Río Quijos, above the confluence with the Río Papallacta, there are large blocks of skarn rock up to 5 × 3 × 3 m in size. These are the classic calcic magnetite skarns noted in the Río Mulatos (Llanganates) (Litherland, 1987, 1988) comprising pinkish garnet-rock sectors, divided, tectonically, from greenish epidote-rich and dark amphibole-magnetite-rich sectors; all percolated by quartz and calcite veins. It is probable that these blocks are derived from the northern extension of the Urcucocha field (above).
- (c) In the Río Chalpi de Oyacachi there are small blocks of skarn type lithologies, and better-developed examples of massive garnet-?pyroxene-calcite-epidote skarn assemblages occur downstream as blocks in the Río Oyacachi. These blocks indicate the existence of a skarnfield at the headwaters of the Río Chalpi, to the north, and possibly in the south (the geotraverse was along the north bank of the Río Oyacachi).
- (d) A new skarnfield was located on the western slope of Sara Urco mountain about 1 km from the summit. Garnet-rich and epidote-rock types are present along with black marbles. On Map 1 the occurrence is shown as an isolated klippe.
- (e) In the Río Diviso, east of Sara Urco, there are blocks of calcic magnetite garnet-epidote skarns and pale calc-silicates. A glance at Map 1 shows it is unlikely that these are derived from the Sara Urco field, and thus another skarnfield to the east of Sara Urco can be tentatively proposed.

Thus the 1988-1989 geotraverses in the north have been successful in tracing the Llanganates skarn belt for a further 120 km along strike from the Llanganates. Studies of the Urcucocha field show that the skarn rocks are preserved as a synformal klippe. Dips are steeper at the Sara Urco field and field evidence for a synform is wanting. However, the absence of skarn rock outcrops in the major valleys of Papallacta and Oyacachi indicate that the outcrops occur at high topography level from Urcucocha to Sara Urco and thus the interpretation of all the skarnfields as isolated klippe is justified. On this model there should be a skarnfield between the Oyacachi and Papallacta rivers.

Epidote-rich rocks were noted along the Papallacta-Baeza road and along the Río Oyacachi (junction with Río Santa María). These “proto-skarns” are almost certainly related to the effects of the Azafrán-type plutonic belt of the sector on the host greenstones.

Blocks of pale calc-silicates, marbles and dolomites have also been noted in the northern rivers draining the Central belt (Map 1, Table 1). The marbles vary from white through grey to black in tone and are associated with the skarns, or derived from lower levels of the nappe complex. The black marbles of Sara Urco superficially resemble those of Cerro Hermoso (Litherland, 1988).

2.3.6 Serpentinities and associated rocks from the Central and Eastern Belts

More float block occurrences have been noted in the northern Cordillera Real and various serpentinite divisions or bands can be proposed within the Central and Eastern belts of the Cordillera Real. Samples from some of these belts have been analysed in the nationwide study of ultramafic-mafic complexes (Appendix 1, Table 1). The following divisions are proposed (excluding the Peltetec division of the Western belt).

- (a) The Soledad serpentinite division is represented by outcrops in Quebrada Soledad south of Antisana (Maps 1 and 4). At the studied outcrop 8 m of serpentinite dips at about 45° to the west with an exposure gap to the west of 20 m followed by another 2 m of serpentinite. Thus, the total serpentinite could be 30 m. To the west and east are grey and black phyllites with thin quartzite laminae; the serpentinite contact is parallel to S₂ in the phyllites. Looking along strike it can be seen that the serpentinite (which stands out as rocky crags) is not present in one creek and is in the form of lenses.

The Soledad division lies within the belt of Tres Lagunas granitic/gneissic rocks. To the north and south, along strike and within the same rocks, blocks of serpentinite have been found in rivers and streams and these are provisionally correlated with the Soledad belt. The occurrences from north to south are:

- (1) Río Cariyacu (Map 3): blocks up to $2 \times 1 \times 1$ m.
- (2) Río Chalpi de Papallacta: small serpentinite and hornblendite blocks
- (3) Río Quijos upstream from Río Papallacta: blocks up to $4 \times 4 \times 2$ m.
- (4) Quebrada Soledad: outcrop (see above).
- (5) Río Mulatos: see Litherland (1987; 1988).
- (6) Quebrada de los Incas (Río Muyo west of Cerro Hermoso): see Litherland (1988).

Serpentinities of the Soledad division are essentially massive, speckled, dark grey/green rocks comprising fine-grained serpentinite with highly altered orthopyroxene relics. Carbonate (?magnesite) may be present as isolated crystals, more rarely as veins.

- (b) The Urcucocha serpentinite division is represented by small blocks of serpentinite in the headwater streams east and west of the skarn *serranía* (Serranía Urcucocha, Maps 1 and 4). It can be assumed that a thin outcrop of serpentinite occurs below the structural base of the skarn. Blocks of ultramafic schists and asbestiform tremolite-serpentinite rocks are also present. The serpentinite is more strongly sheared than that of the Soledad belt, with carbonate and talc becoming predominant elements.

- (c) The sub-Andean serpentinite division is manifested by the incoming of enormous serpentinite blocks up to $6 \times 5 \times 5$ m in size in the lower reaches of the Río Cosanga. Serpentinite blocks in the Río Aliso and Río Bermejo (Map 1) may also be derived from this belt. The blocks in the Río Quijos upstream from Baeza (see also Colony and Sinclair, 1932) may also belong to this belt but efforts to trace them to a nearby source have failed and they are thus thought to be derived from the Soledad belt.
- (d) The Zumba ultramafic division is exposed in the south of the Cordillera Real along the main road east of Zumba (Map 8) in the form of minor outcrop of serpentinites, olivine pyroxenites, tremolitic ultramafic rocks and gabbros. The division defines the eastern fault which divides the Tertiary Zumba basin from the Isimanchi (metamorphic) division. Further east, near the junction of the Río Isimanchi and Río Mayo, there are xenoliths in the Río Mayo batholith which include hypersthene gabbros and strongly chloritised and epidotised rocks which may relate to the Zumba ultramafic division.

The Micacocha-Cosanga traverse (Map 4) showed that the nappe complex of the Central belt and the steep Eastern belt contain three serpentinite divisions, all with the same basic lithological and compositional characteristics. Within the scheme of the nappe complex (Figure 2) it can be suggested that these units represent imbricate slices of a common serpentinite body.

2.3.7 Pre-Cretaceous volcano-sedimentary rocks of the Eastern Belt

The exact relations of the “pre-Cretaceous” rocks across the sub-Andean front remains, to a certain degree, a topic of speculation. For this reason, those lying to the east, i.e. within the Eastern belt, are treated separately here.

In the north, the “cratonic” Misahuallí unit of Jurassic continental andesites, rhyolites, agglomerates and tuffs can be traced west across the “cratonic front” (Map 1) into the Eastern (sub-Andean) belt along which Tertiary thrusting has also affected Cretaceous formations. Moving west the sheared Misahuallí is replaced below the Hollín Formation by a sequence dominated by greenstones and cleaved green agglomerates and further west by greenstones, greenschists, metagreywackes and minor marbles, a sequence which also resembles the greenstones at the base of the nappe pile in the Central belt (Table 1). Thus, there exists the possibility that the all three volcanic sequences are essentially the same age.

In the south the continental volcanic rocks related to the sub-Andean volcanic-plutonic division are separated from an “older metasedimentary division” now referred to as the Isimanchi division on Map 8. The volcanic sequences comprise mainly andesites with lesser dacites and possible basaltic andesites. East of Limón and Copal, within the Eastern belt, the volcanics/volcanoclastics are interstratified with marbles, and, as in the north, become progressively deformed. The metasedimentary rocks of the Isimanchi division, which also appear in the Eastern belt, consist of low-grade, regionally metamorphosed volcanoclastic sediments and some volcanics with significant marble horizons.

2.3.8 Pre-Cretaceous calc-alkaline plutonic rocks of the Central and Eastern Belts

In the north this is represented by the Abitagua batholith and the Azafrán complex; in the south by the Zamora-Río Mayo batholith.

- (a) The Abitagua batholith, ca. 160 Ma (Litherland, 1988), is an essentially undeformed granite/diorite body intruding continental volcanics (presumably the Misahuallí unit) and lying within the “cratonic” zone.
- (b) The Azafrán complex has been traced from Azafrán (Río Pastaza) northwards of the Río Mulatos (Litherland, 1988). There are no outcrops on the Antisana-Cosanga and Papallacta-Baeza sections, but further north along the Ríos Oyacachi and Salado outcrops and blocks of Azafrán-type lithologies were noted. These are dominated by granodiorite and diorite, gneissose in places and carrying mafic xenoliths. Gabbros, hornblendites and granites are subordinate, although gneissose granites predominate in the Río Oyacachi. In the Río Diviso the diorite intrudes feldspathic porphyry, similar to rocks noted in Río Chalupas and similar in composition to the quartz-monzonite of Azafrán quarry. Another minor lithology typical of Azafrán is a medium grained diorite with euhedral hornblende crystal up to 1 cm in length.

The outcrop pattern of the Azafrán-type rocks on Map 1 can be interpreted in terms of structural levels; at higher levels the plutonic rocks are covered tectonically by the nappe sequence. If this is the case then the Azafrán plutonic complex represents a major batholith of over 150 km in length.

- (c) The Zamora-Río Mayo complex is extensively exposed in the south and is mantled by its volcanic and subvolcanic products. The entire plutonic suite is considered to be essentially “I-type”, i.e. subduction zone related, and typically the plutonic rocks range from diorite/quartz diorite to granodiorite in composition. True granites are extremely rare.

2.3.9 Cretaceous to Lower Tertiary Formations of the Eastern Belt

These include the Cretaceous Hollín and Napo Formations and the upper Cretaceous to Lower Palaeocene Tena Formation. In the north all three units are present; west to the “cratonic limit” (Map 1) they are deformed by the Tertiary thrusting along the Eastern (sub-Andean) belt.

In the south the picture is similar and in the far south the presence of both the Hollín and Napo Formations has been confirmed palaeontologically (see 2.3.10). Thus, in the Ríos Vergel and Panguri (Map 8) the ammonite-bearing mudstones are attributed to the Napo Formation and the blocks of clean, white to pale red sandstones to the Hollín Formation, and thus these units are more widespread in SE Ecuador than was previously supposed.

2.3.10 New ages from the Central and Eastern Belts

- (a) Devonian K-Ar ages (Appendix 8) are noted from amphibolite dykes near Papallacta. Whilst this packet of rocks which includes the Tres lagunas suite, is of higher grade than the surrounds, it is premature to interpret it as older basement on these dates alone.
- (b) Triassic bivalves of possible Norian age have been identified in the Río Piuntza, east of Zamora (Appendix 9, No. WH/89/-28R), within calcareous limonites; this has been interpreted as a megaxenolith within the Zamora batholith and possibly equivalent to the Isimanchi division.
- (c) Jurassic ammonites of Sinemurian age have been identified from the Santiago Formation (Appendix 9, No. WH/89/85R).
- (d) Jurassic K-Ar ages are recorded for the Abitagua, Río Verde (Azafrán), Zamora and Río Mayo batholiths (Appendix 8), thus broadly confirming the Rb-Sr ages (Litherland, 1988). However, whilst the Rb-Sr age “fixes” the Abitagua batholith at ca. 160 Ma the new K-Ar ages continue to suggest a younger 120 Ma “event” at Azafrán. For the Zamora-Río Mayo batholith there is a spread from 195-125 Ma (Early Jurassic - Early Cretaceous).
- (e) Cretaceous K-Ar ages are numerous (Appendix 8), but many are thought to relate to resetting. The Pimampiro pluton in the Central belt near Ibarra gives a mean age of 81 ± 3 Ma, very similar to that of Magtayán in the Western belt (see 2.2.5). A similar age, ca. 80 Ma, is indicated as a resetting event of the Tres lagunas granite at Peggy Mine and the Agoyán garnet gneiss, both close to the Baños front. The basement of Sabanilla-Valladolid also indicates this resetting event.
- (f) Cretaceous ammonites (Middle Albian) have been recorded from the Napo Formation of SE Ecuador (Appendix 9, No. WH/88/416R). Cretaceous palynomorphs were also noted from the same samples (Appendix 9, No. WHI/89/89R).
- (g) Lower Tertiary K-Ar ages (Appendix 8) are indicated for certain essentially undeformed post-tectonic stocks and small plutons in the Central belt, and thus provide a minimum age for the regional metamorphism. These new ages essentially support those of Kennerley (1980) and, Herbert and Pichler (1983) listed in Litherland (1987). The plutons are those of San Lucas, Amaluza, and two unnamed granodiorite stocks along the Limón-Gualaceo and Loja-Catamayo roads (Map 8), as well as the Pungalá pluton of the Western belt (see 2.2.5). All show K-Ar ages broadly in the 40-60 Ma range. The Azafrán complex shows reset dates in this range.
- (h) Upper Tertiary K-Ar ages (Appendix 8) are thought to reflect the intrusion of the Portachuela batholith (Map 8) and the resetting of the Chingual and Sacha plutons which lie along the Colombian border.

2.4 Tectonics

The schematic section across the northern Cordillera Real (Figure 2) interprets the “steep belt” of the Llanganates and Sara Urco-Río Salado sectors as structurally below the “flat belt” of the Oyacachi-Cosanga sector. The nature of the along-strike transition from steep foliations at Azafrán and Cerro Hermoso (where there is one phase of folding with steep axial planes) northward to the Río Cosanga where structures are flat, and related to the second foliation, has yet to be mapped, but the scheme on Figure 2 is the most probable interpretation following the lines of modern thrust tectonics (e.g. Butler, 1983). It interprets the transition as a duplex roof thrust (De Paor, 1988) of D2 age flowing over steep D1 structures (Cerro Hermoso). Hopefully further project work can define the contact in the Río Chalupas area. Thus, the flat belt area is interpreted as a major plunge depression marked by the presence of high-level thrust sheets such as the Llanganates skarns exposed as erosional klippen.

In the south of the Cordillera Real the tectonic pattern is of essentially steep D2 structures, although zones of flat cleavages exist. Fault-bounded lenses, interpreted to represent horses (Butler, 1983), have been recognized, and it seems probable that the rocks in the south are controlled by eastwards imbricate stacking in the same manner as the steep belt on Figure 2.

2.5 Regional interpretation

Elements to be taken into account in any evolutionary model for the Cordillera Real can be summarized from west to east as follows:

- (a) In the Western belt the Peltetec ophiolitic “suture” separates W-thrusted continental sediments (Guamote, Cebadas and Guasuntos divisions) from “forearc” (Maguazo) and “island arc” (Alao-Paute division) units of Oxfordian-Callovian age. These rocks are buried by Upper Cretaceous (Yunguilla Formation) sediments near Cuenca.
- (b) The Central belt comprises a thrust sequence involving S-type granites (Tres Lagunas), with possible older basement at Papallacta, thrust over skarn rocks and continent-derived sediments (Loja division), in turn thrust over “island arc” units of the Azafrán plutonic complex and associated volcanics, greywackes and marbles. There are thin serpentinites along thrust planes.
- (c) In the sub-Andean belt, the Azafrán “arc” rocks are thrust against a sub-Andean continental volcanic-plutonic arc of Jurassic age. There may be a stratigraphic facies change from west to east linking the Azafrán “island arc”, the sub-Andean continental arc and the Lower Jurassic Santiago/Chapiza unit further east.

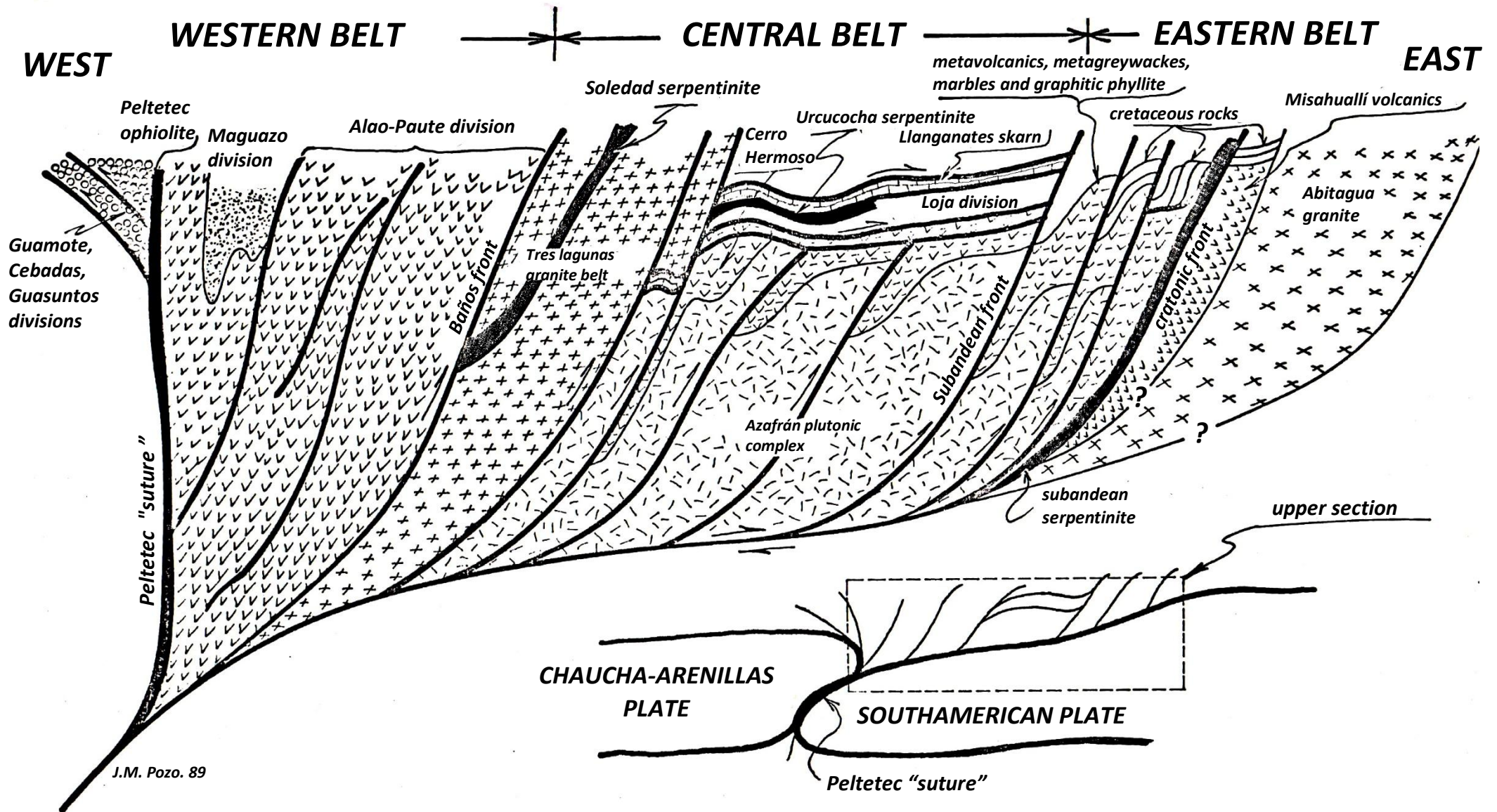


Figure 2. Schematic section across the northern Cordillera Real based on the continental collision model.

The lithological and structural data outlined above are still best fitted into a continent-continent collision model (Figure 2), in which the various elements are finally swept into the collision zone between the South American and Chaucha-Arenillas continents probably in Late Jurassic times (pre-Hollín Formation). As pointed out in Litherland (1988) the nature of the thrust belt suggest that the overriding plate was the Chaucha-Arenillas, not the South American, as would be predicted on Cenozoic patterns.

The presence of imbricate thrusts of Cretaceous units along the sub- Andean zone could be used as an argument for a Tertiary (collision) orogeny involving Jurassic and Cretaceous elements. This can be ruled out over the Western belt by the presence of the unconformably-overlying Yunguilla Formation of Upper Cretaceous age, and, over the Central belt, by the presence of undeformed Lower Tertiary intrusives. Thus, it seems likely that the sub-Andean belt represents Tertiary rejuvenation of the older (Jurassic) collision faults during the process of Late Tertiary Andean uplift.

Map 1, whilst not claiming to be an accurate geological map, points the way ahead for future geological research in the cordillera; a tectonic stratigraphy can be elucidated with potential marker bands: skarn, serpentinite, marble, etc. Moreover, in terms of regional understanding, the recognition of the Loja division in the northern nappes is particularly significant. It is clear from Figure 2 that whilst the complex thrust tectonics presents difficulties in defining a “classic” stratigraphy, attempts can be made to “restore” such sections to pre-tectonic positions and help define the details of the geological history.

Elements of the “collision” model can now be traced along the Cordillera Real as far as Peru. Thus the Alao-Paute division, Baños front and Tres Lagunas suite do not appear to cross westwards toward the Raspas “suture” of the El Oro metamorphic belt (see Litherland, 1988, Appendix 1), but rather appear to truncate the El Oro trend in the form of the Las Aradas fault thus, indicating both a southern continuation of the Chaucha-Arenillas block to the west, and an extension of the collision belt into northern Perú.

3. MINERAL OCCURRENCES AND GEOCHEMICAL ANOMALIES

As in Litherland (1987, 1988) the mineral groupings follow those of the Mining Journal. Only mineral occurrences and geochemical anomalies found by the Project, or in project-related studies, over the period in question, are noted here. These occurrences are integrated with previous Project information and extra-Project information under Chapter 4.

3.1 Precious metals

3.1.1 Gold and silver

In the regional (geotraverse) survey, gold was panned by the Project teams, or seen being worked, from many rivers. The gold occurrences in the south are shown on a special map (Map 10) and those in the north included on Map 1.

Certain rocks collected over the geotraverses show the following gold and silver traces:

- (a) Of the ultramafic/mafic suite (Appendix 1, Table 1), the highest Au value was 176 ppb from a Tampanchi pyroxenite.
- (b) Over the new Llanganates skarn occurrences, values of 0.35 ppm Au are reported from blocks in the Río Quijos and up to 8 ppm Ag from outcrops of the Urcucocha skarnfield (Appendix 1, Table 4).
- (c) Cu mineralization in Azafrán-type granites in the Río Oyacachi yielded 0.35 ppm Au (Appendix 1, Table 4).
- (d) Samples from sulphide-rich shear zones in the Portachuela batholith near Laguna Cox carry up to 50 ppm Ag and up to 480 ppb Au (Appendix 1, Table 3). These are exposed along the track which leads eastwards to Zumba (Map 13). The shears strike between 20° and 50° and generally dip moderately to the east. The zone of mineralisation, which consists principally of pyrite, chalcopyrite and sphalerite, is several metres wide and is associated with late andesite dykes and feldspar porphyries which cross-cut the batholith. The samples were collected from the south bank of the Río Isimanchi, and the red weathering, oxidised, sulphide zone can also be seen on the north bank, ca. 750 m upstream from the junction of the Río de Los Colorados.
- (e) On the south bank of the Río Mayo near the Palanda road, 1.12 ppm Au is reported from a 1 mm Cu-rich vein in granodiorite (Appendix 4).
- (f) There is a fluvial anomaly of 19 ppm Ag (Appendix 2, No. F111) from the Río Chalpi de Papallacta.

- (g) There is a fluvial anomaly of 12 ppm Ag (Appendix 2) from the Río Cosanga (Map 4).
- (h) There is a fluvial anomaly of 7 ppm Ag (Appendix 2) in the Río Azuela (Map 5).
- (i) Fluvial Ag anomalies of 5 and 4 ppm were detected in the Río Diviso and Arroyo El Tuerto confluence (Map 7). The rivers drain the Azafrán “island arc” complex.
- (j) Fluvial sample A-108 gave 4 ppm Ag concordant with Zn-Pb anomalies (Appendix 2). The sample comes from a small creek draining the Río Santa Bárbara upstream from Mina Peggy (see Map 13 in Litherland, 1988). The streams drain an outcrop of Tres Lagunas granite but the anomalous Zn-Pb suggests the extension of Peggy Mine-type mineralisation.
- (k) A geochemical (fluvial) anomaly of 4 ppm Ag concordant with anomalous Zn (205 ppm) (Appendix 2) was analysed from sample A-206 from the Río Boliche (Map 11 in Litherland, 1988).

On the follow-up survey by Clarke and Viteri (Appendix 4), the following gold and silver values were assayed from rocks collected from mines and prospects:

- (a) At Peggy Mine values up to 0.66 ppm Au and 222 ppm Ag were recorded, with an Au:Ag ratio of 1:100.
- (b) Over the Río Ayllón area (tributary of Río Santa Bárbara, near Peggy Mine) values of up to 635 ppm Au and 246 ppm Ag were recorded, with an Au:Ag ratio of 2:1. Samples were collected from river blocks and ore stockpiles.
- (c) At the Nambija Mines values of up to 442 ppm Au and 17 ppm Ag were recorded, with an Au:Ag ratio of 15:1. Samples were collected mainly from the Arco, Playón and Mapasingue workings.
- (d) At Chinapintza gold prospect values of up to 363 ppm Au and 250 ppm Ag were recorded. It is noteworthy that the silver was found contained in galena.
- (e) At Piuntza gold prospect values of up to 7.32 ppm Au and 38 ppm Ag were recorded.
- (f) At Los Planes gold prospect values of up to 233 ppm Au and 62 ppm Ag were recorded.

3.2 Older major metals

3.2.1 Copper

- (a) Values of up to 6.38 % Cu were recorded from samples from Peggy Mine and up to 0.36 % Cu from the Río Ayllón area (Appendix 4). The Cu-bearing minerals chalcopyrite, stannite and bournonite (PbSbCuS_3) were noted (Appendix 6).
- (b) 7189 ppm Cu was recorded (Appendix 1, Table 3) from a mineralized float block of Tertiary felsic volcanics in the Principal area (Litherland, 1988, Map 12).
- (c) Chalcopyrite was noted and values up to 2873 ppm Cu were recorded from the mineralised sulphide-rich shear zone (see 3.1.1) in the Portachuela batholith (Appendix 1, Table 3).
- (d) 0.1 % Cu was recorded from a mineralised Azafrán-type orthogneiss from the Río Oyacachi (Appendix 1, Table 4).
- (e) In the Río Chalpi de Oyacachi float blocks of black ferruginous schists contain trace of chalcopyrite and azurite (Map 3).
- (f) Float blocks of epidotised greenstones (“proto-skarn”) with small sulphide/chalcopyrite mineralisation were noted in the Ríos Oyacachi and Santa María (Map 3).
- (g) Cu values of 840 ppm and 499 ppm were obtained from stream sediments from the Quebradas San Roque and Napurca respectively: tributaries of the Río Yacuambí (Appendix 2) (Litherland, 1988, Map 15). Background is in the region of 50 ppm Cu. The streams drain the Zamora volcano-plutonic complex.

3.2.2 Lead and zinc

- (a) In the follow-up survey (Appendix 4) values up to 1.06 % Pb and 31.1 % Zn were obtained from samples from Peggy Mine; up to 1.72 % Pb and 3.07 % Zn from the Ayllón area; and up to 0.11% Pb and 5.27 % Zn from Chinapintza. Minerals identified included boulangerite, galena, sphalerite and bournonite.
- (b) Samples from the mineralised zone of the Portachuela batholith (see 3.1.1) yield up to 1086 ppm Pb and 915 ppm Zn (Appendix 1, Table 3). Sphalerite was noted in the field.
- (c) Epidote rocks from the Urcucocha skarnfield (Map 4) analyse up to 840 ppm Zn (Appendix 1, Tables 2 and 4).
- (d) “Anomalous” stream sediment values range up to 320 ppm Pb and 395 ppm Zn (Appendix 2). The highest Zn value is from the Río Aliso (Map 4).

3.2.3 Tin

On the follow-up survey (Appendix 4), values of up to 7684 ppm Sn were noted from samples from Peggy Mine, where cassiterite and stannite were identified. “Common” cassiterite in a pan concentrate from the Río Pichanal east of Saraguro confirmed a previous tin anomaly (UNDP, 1972).

3.3 Steel industry metals

3.3.1 Chromium

While the ultramafic bodies average about 1000 ppm Cr (Appendix 1, Table 1), one sample from the Urcucocha belt yielded 4079 ppm, but this is only just above levels (1000-3000 ppm) standard for world- wide ophiolite complexes (Hutchinson, 1983).

3.3.2 Cobalt

Float samples from skarn rocks in the Río Quijos give “anomalous” Co values up to 1100 ppm (Appendix 1, Tables 2 and 4).

3.3.3 Iron and manganese

- (a) Magnetite is present in skarn blocks in the Ríos Quijos and Oyacachi and in the Sara Urco field, but no large blocks of magnetite rock were noted.
- (b) The Fe and Mn analytical values (Appendix 1) do not indicate samples of economic interest.

3.3.4 Molybdenum

- (a) The field traverse across the Urcucocha skarnfield (Map 4) from the summit of the ridge east to Laguna Urcucocha presents a wall of exposure on the southern flank of the pass. This comprises mainly massive, green epidote rock, with a subhorizontal fracture foliation, derived from a protolith greenstone. Fine, disseminated molybdenite together with larger (up to 1 cm) pyrite crystals are present in the rock outcrop over a lateral distance of at least two metres but probably less than 10 m. Fracture surfaces show a soft, pinkish-weathering mineral. Analyses show 3000-5000 ppm Mo (Appendix 1, Table 2). It is interesting to note the “anomalous” Mo value of 27 ppm from the adjacent serpentinite division (Appendix 1, Table 1).
- (b) “Anomalous” Mo values of ca. 20 ppm occur (Appendix 2) from stream sediments of the Río Diviso (Map 7).

3.3.5 Nickel

Values (1000-3000 ppm) of Ni in ultramafic rocks (Appendix 1, Tables 1 and 4) are typical of ophiolites (Hutchinson, 1983) and of no economic interest.

3.3.6 Tungsten

In the follow-up survey, scheelite was noted in many of the panned samples from the areas of Peggy Mine, Ayllón, Los Planes, Malacatos and Saraguro (Appendix 4, Table 1); the Ayllón results are particularly interesting. Rock samples from Peggy Mine gave up to 5979 ppm W; wolframite was identified comprising 60-70 % ferberite (Appendix 6).

3.3.7 Vanadium

- (a) It is interesting to note the anomalous values of up to 1900 ppm V from the Mo-bearing skarn rocks (Appendix 1, Tables 2 and 4). However, these are of no economic interest.
- (b) There are vanadium stream sediment anomalies of 296, 316 and 655 ppm which correlate with Fe and Ti anomalies (Appendix 2) from samples draining the plutonic-volcanic complex of Río Mayo; with the Hollín Fm. represented as float blocks (Map 11). The Fe and Ti anomalies may relate to ilmenite in the plutonic-volcanic rocks but the source of the high vanadium is not known.

3.4 Fuel minerals

3.4.1 Oil

- (a) Both the Santiago Formation of the Cutucú uplift along the new road from Pituca to Santiago, and the Napo Formation in the Río Vergel to the south of La Canela (Map 11), smell strongly of hydrocarbons and therefore may have some source potential. No geochemistry is available for these samples, but the palaeontological reports are included in Appendix 9.
- (b) Certain blocks of the Napo Formation in the Río Salado (Map 7) smell of hydrocarbons.

3.5 Electrical metals and minerals

3.5.1 Cadmium

Samples from Peggy Mine yield up to 0.265% Cd (Appendix 4).

3.6 Chemical metals and minerals

3.6.1 Antimony

- (a) Values up to 0.49 % Sb were reported from samples from the Ayllón area (Appendix 4); the minerals boulangerite and bournonite were identified.
- (b) “Anomalous” Sb values (13 ppm) corresponding to “anomalous” Bi values occur in a sample of skarn from the Río Oyacachi (Appendix 1, Table 2), and the two samples from the mineralised zone in the Portachuela batholith (see 3.1.1) (Appendix 1, Table 3) which gave 402 and 53 ppm Sb.

3.6.2 Bismuth

- (a) The follow-up survey reported up to 0.58 % Bi from Peggy Mine samples. Bismuthinite was identified (Appendix 4).
- (b) “Anomalous” Bi values, corresponding to “anomalous” Sb values, occur in a sample of skarn from the Río Oyacachi (14 ppm) (Appendix 1, Table 2), and the two samples from the mineralised zone in the Portachuela batholith (see 3.1.1) (Appendix 1, Table 3), which gave 12 and 29 ppm Bi.

3.6.3 Kaolin

Again, weathered, kaolinitic, microfeldspathic porphyries and dykes have been reported. In the Río Salado (Map 7), a 1 km thick, subvertical sheet of feldspathic porphyry shows strongly-weathered kaolinitic profiles in certain sectors.

3.7 Insulants and refractories

3.7.1 Asbestos

Small blocks of tremolite asbestos occur in Quebrada Chiriyacu (Map 4), and small veins (1 cm) of antigorite asbestos were noted in serpentinite blocks in the Río Cosanga headwaters. Neither occurrence is of economic interest.

3.7.2 Graphite

Graphite is common in the metamorphic rocks of the cordillera. Bands of higher grade, up to 1 m thick, were noted in Quebrada El Tuerto (Map 7) but are unlikely to be of economic interest.

3.8 Other industrial minerals, rocks and gemstones

3.8.1 Carbonate

- (a) In the sub-Andean belt, there are abundant outcrops of Napo Formation black limestone.
- (b) The metamorphic rocks of the Central belt contain carbonate horizons normally noted as minor float blocks. The sizes of the block indicate band(s) less than one metre thick. Black marbles were found at Sara Urco associated with the skarns. In the Río Diviso and Arroyo Tuerto (Map 7) there are blocks of pure, white, medium-grained marble.
- (c) Much of the carbonate marker in the nappe complex of Table 1 appears to comprise rusty-weathering, impure dolomite.
- (d) Small travertine occurrences have been noted (Maps 3 and 4) but are of no economic significance.

3.8.2 Garnet

Once again, garnet-rock of high-purity has been noted as an important element in the northern skarnfields. However, the lithology is normally found as tectonic bands not more than 20 cm thick.

3.8.3 Quartzite

The Hollín Formation is of potential importance for the glass industry.

3.8.4 Ornamental stone

Without going into any detail, there are various “attractive” stones derived from major geological units. These include the Tres Lagunas granitic suite (blue quartz, smoky feldspar); the Abitagua granite (sites with pink feldspar megacrysts); and the various pink-green-black varieties of skarn rock.

3.8.5 Talc

There are small blocks of talc schist in Quebrada Ñancarayacu and talc-rich serpentinite blocks at the headwaters of the Río Cosanga (both on Map 4). Neither is of economic interest.

3.8.6 Tourmaline

Tourmaline (schorlite) has been noted in rocks associated with the Tres Lagunas granite suite (2.3.2). The best-developed quartz-tourmaline veins and balls were seen in Quebrada Macuchi (Map 14); tourmaline crystals reach 2 cm in length. Follow-up studies have also located tourmaline-bearing material (Appendices 4-7).

Tourmaline (schorlite) was also noted in late micropegmatites within the mica schists of Sara Urco (Map 6), close to the skarnfield.

No gem quality tourmaline was noted.

4. REGIONAL MINERAL POTENTIAL

4.1 Introduction

Whilst new data on the mineral potential of the Cordillera Real continues to be provided both by the Project and the private sector, regional classification appears to become more difficult. This is because of the increasing evidence that many of the important mineral prospects within the metamorphic province relate to younger Cenozoic volcanism. Thus, the distribution of metal deposits over the Cordillera Real probably relates to many factors e.g.:

- (1) Metallogenic processes in the basement, prior and related to the “collision” orogeny, e.g. the Llanganates skarns.
- (2) The Cenozoic igneous activity related to subduction of the Nazca plate, i.e. the “Bolivian model” with metal input possibly from the mantle.
- (3) The Cenozoic concentration, or reconcentration, of metals along the old collision structures, e.g. Baños Front.

In the following section the mineral potential of the Cordillera Real is related to basement units or structures rather than to age. The system of mineral belts proposed in Litherland (1988) is thus replaced by the following (Figure 3):

- (a) Ultramafic rocks: precious metal potential.
- (b) The Alao-Paute “island arc”: polymetallic potential.
- (c) The Azafrán “island arc”: polymetallic potential.
- (d) The Baños front: gold potential.
- (e) The Tres Lagunas granite suite: tin-tungsten potential.
- (f) The Zamora-Abitagua continental arc: gold potential

4.2 Ultramafic rocks: precious metal potential

4.2.1 *The Tampanchi ultramafic complex*

As predicted in Litherland (1988) work by a private company has indicated precious metal (Au, Pt, Pd) anomalies over certain sectors of the Tampanchi complex; thus, accounting for the reports of gold and platinum in the rivers around Pindilig (Navarro 1986, Vol III).

As reported in 2.2.4, certain aspects of the Tampanchi geology favour its interpretation as an Alaskan-type ultramafic pipe. Hopefully K-Ar determination will indicate either a syntectonic (?ophiolitic) or post-tectonic (?Alaskan pipe) age. If the age approximates to 80 Ma then a chain of pipes/intrusives could be proposed including those of Magtayán and ?Pimampiro.

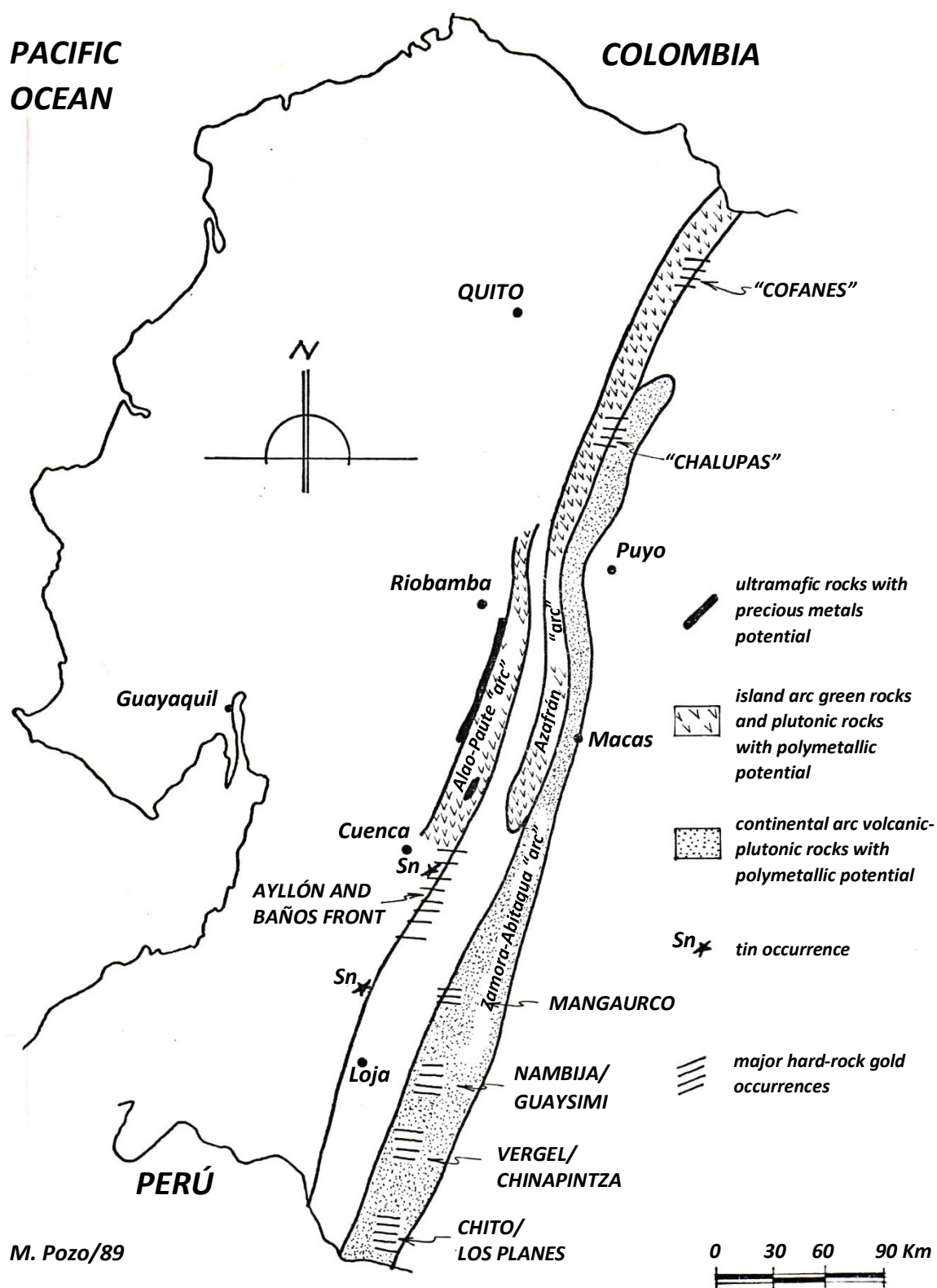


Figure 3. Mineral belts in the Cordillera Real related to major basement geological elements

As reported in 2.2.4, certain aspects of the Tampanchi geology favour its interpretation as an Alaskan-type ultramafic pipe.

Whatever the interpretation, the project has discovered a source of precious metals and a careful eye will be kept for Tampanchi-type lithologies, particularly as float blocks, in other parts of the cordillera.

4.2.2 The Peltetec ophiolitic belt

No further work has been undertaken over this sector, the mineral potential of which is discussed in Litherland (1987, 1988).

4.2.3 Ultramafic rocks of the Central and Eastern belts

The new serpentinite divisions (see 2.3.6) appear to be of limited thickness and of limited mineral potential (see analyses, Appendix 1, Table 1), and whilst they cannot be ruled out as a gold source it is unlikely that they represent a significant one.

4.3 The Alao-Paute “island-arc”: polymetallic potential

Rocks of the Alao-Paute divisions of the Western belt correspond to an island arc sequence of metamorphosed andesites, pelitic and carbonaceous shales and thin marbles. There are no obvious candidates for the plutonic phase.

Whilst stratabound sulphide mineralisation has been noted (Litherland, 1988), Alao-Paute-hosted mineralisation is generally seen to be of Cenozoic age and of polymetallic (Pb-Zn-Cu-Ag) type, typified by the epithermal San Bartolomé and Pilzhum prospects, and referred to as the Altar-San Bartolomé polymetallic belt (Litherland, 1988). A hypothesis was proposed (Litherland, 1988) that the Cenozoic poly-metallic mineralisation represented the scavenging of base metals from the Alao-Paute rocks by volcanic fluids along older “collisional” faults, which were thus recommended as prospection sites.

During the year in question (Appendix 4), visits were made to Peggy Mine, close to the Baños front which tectonically divides the Alao-Paute rocks from those of the Tres Lagunas granite suite. Base metals, especially copper, lead and zinc sulphides, occur as cross-cutting veins, stockworks and breccias within the granite and are probably related to the intrusion of porphyry bodies of presumed Cenozoic age. Tourmaline is very common, even postdating the porphyry, and wolframite and stannite are present. Clarke (Appendix 4) considers the locally high tin, tungsten and silver values (e.g. in sample MC2) to be similar in ore element suite and sub-volcanic association to Andean sites such as Antamina in Peru and the Cordillera Real of Bolivia.

Further east at Ayllón and Portachuela, away from the Alao-Paute division, there are polymetallic occurrences with antimony.

Thus, the Alao-Paute island arc-hosted mineralisation corresponds to syn-deposition, syn-collisional and post-collisional (Cenozoic) ages. The latter appears to be centred on small porphyry stocks of acid to intermediate composition with hydrothermal (epithermal) breccias and wallrock alteration. The eastward “zonation” from Cu- Pb-Zn-Ag types through Cu-Zn-Sn-W-Bi (Peggy) to Zn-Pb-Au-Sb (Ayllón), away from the Alao-Paute rocks, may relate to host rock composition.

4.4 The Azafrán “island-arc”: *polymetallic potential*

4.4.1 Introduction

The “Azafrán island arc” provisionally describes the Azafrán-type calc-alkaline plutonic and subvolcanic rocks in the north of the Cordillera Real and their mantle of greenstones, metagreywackes, phyllites, schists, skarns and epidotic rocks. It appears that these rocks can be traced from the Colombian border south through the Guamote-Macas traverse (Litherland, 1987), but they are not present south of the Cuenca-Limón traverse (Map 8). Mineralisation appears to be confined to pre-collisional and syn-collisional phenomena.

4.4.2 The Llanganates skarn belt

The project both discovered and traced this belt, in the form of individual skarnfields, for about 150 km. In the south, in the Llanganates, the first field to be discovered was that of El Placer (Litherland, 1987, 1988) to the west of the Río Mulatos. A mining company has since discovered a field to the east of the same river.

This report (2.3.5) describes the discovery of the new fields further north, the Urcucocha and Sara Urco, as well as float block evidence for other fields.

Outcrops take the form of high level klippe (Map 1), i.e. topographically-isolated tectonic thrust sheets, which accounts for the lack of skarn outcrops along the major valleys, e.g. Papallacta and Oyacachi. The main (subhorizontal) foliation is of D2 age.

The skarns are of calcic magnetite type derived from a mafic volcanic protolith (see petrographic reports in Litherland, 1987, 1988). Skarn rocks are intercalated, tectonically, with marbles, calc-silicates, metavolcanics of mafic to acid composition (in places with late biotite porphyroblasts), pelitic schists, greenschists, graphitic schists and meta-diorites. Thicknesses of the skarn tectonic packets are over 160 m in El Placer, ca. 300 m at Urcucocha and ca. 200 m at Sara Urco. At El Placer and Urcucocha it can be demonstrated that skarn rocks comprise more than half the packet. Thus, in terms of mineral potential there is a tremendous volume of skarn rocks in each skarnfield. For example, if the Urcucocha field forms the extent of Serranía Urcucocha (the small hill-section on Map 4) then 150 million cubic metres of skarn rock are indicated.

It appears that there is a spacial relationship in the north of the Cordillera Real whereby outcrops of Llanganates skarn are flanked eastwards by Azafrán type diorite-granodiorite batholith(s) and associated greenstones and metasediments of island arc affinity. Following the model of Figure 2 it can be suggested that the Llanganates skarns represent the same island arc volcano-sedimentary pile, metasomatised on the western margin of Azafrán batholith and later tectonically detached and thrust over the batholith.

So far, the geological studies have involved two outcrop-traverses, across the El Placer and Urcucocha fields, and the sampling of float blocks. Apart from the ubiquitous magnetite and pyrite, the El Placer traverse shows enrichment in Cu-Zn-Pb-Ag, with visible chalcopyrite, sphalerite and galena in places, whilst the Urcucocha traverse indicates an outcrop zone (2-10 m) with 0.3-0.5% Mo (Appendix 1, Table 2) in the form of disseminated, visible molybdenite. Gold was recorded in float blocks from the Río Mulatos (Litherland, 1987) but these have not been traced to source; no gold was noted from the El Placer field and the skarnfields and skarn blocks to the north.

In the context of the classification of skarn deposits by the dominant economic metal (Einaudi et al., 1981), the Llanganates belt appears to correspond to the calcic magnetite class, and thus the presence at Urcucocha of Mo-skarns (without tungsten) must be regarded as a “deviation”.

From the mineral data it is clear that from the two outcrop traverses undertaken and float blocks sampled, the Llanganates skarn belt has polymetallic potential and warrants further reconnaissance studies. In this context it is pertinent to note that all the skarnfields are in areas of difficult access, remote from the main roads.

4.4.3 Other epidotised greenstones

Toward the east of the main Azafrán plutonic chain, and straddling the sub-Andean front, there are blocks and outcrops of epidotised, “protoskarn” rocks. Occurrences include the Azafrán area (Río Verde); north through the Río Mulatos (immediately E of the sub-Andean front), near the confluence of the Ríos Quijos and Papallacta; and near the confluence of the Ríos Oyacachi and Santa María. This belt clearly represents the contact metamorphism of the greenstones (meta-andesites) against the main plutonic phase and is associated with widespread quartz/calcite veining and pyrite ± chalcopyrite mineralisation.

4.4.4 Other mineralisation

Stratabound sulphide mineralisation was noted in “Azafrán type” volcano-sedimentary rocks at Cerro Hermoso (Litherland, 1988) and Guamote-Macas (Litherland, 1987).

4.4.5 Conclusions

The probability exists that the rocks of the Azafrán “island arc” can be isolated from the remainder of the Cordillera Real and their mineral potential discussed in this context.

An important element is the Llanganates skarn belt of calcic-magnetite (island arc) skarn formed to the west and thrust over the batholiths along 150 km of strike. The mineral potential of this unit remains to be assessed.

With regard to the remainder of the Azafrán “island arc” there is evidence for stratabound mineralisation and widespread propylitization (epidotisation) of the greenstones which resembles an “Archaean” scenario, vis a vis the adjacent plutonic intrusives. In this context it is pertinent to note that the alluvial gold field of the Río Chalupas (Río Cedroyacu) is possibly derived from these rocks, being too far upstream to be derived from any Abitagua/Misahuallí plutonic/volcanic system. The same probably applies to the Río Cofanes gold field further north, and it is hoped that both these sections will be studied this coming year.

4.5 The Baños Front: gold potential

A gold belt, referred to as the Collay-Shincata belt, and coincident with the Baños front was described in Litherland (1988). During the past year the Río Shincata and Río Betas (Map 14) have been visited and both areas are extensively worked for alluvial gold. Geologically the zone is blanketed by young felsic volcanics of Cenozoic age but basement outcrops consist of strongly sheared granites of the Tres Lagunas suite.

The primary source(s) of gold in the belt is still uncertain but it seems probable that the young volcanics and high level intrusives which cut the Baños front may be an important control on mineralisation.

In the north, the Río Ayllón (Litherland, 1988, Map 13), which has been extensively worked principally for alluvial (? colluvial) gold, and represents the earliest colonial gold prospect, lies slightly to the east of the main Baños front shear zone. This area has been sampled by Clarke and Viteri and the results of their findings are detailed in Appendix 4. Geologically, the main rock type consists of Andean-trending semi-pelites of the Loja division which have a strong, flat to sub-horizontal (at least S2) cleavage, and probably represents a series of stacked thrust imbricates. However, float samples of altered andesitic volcanics and possible hornblende diorites were also noted.

On the east bank of the Río Santa Bárbara, ca. 0.5 km downstream from its junction with the Río Ayllón, samples were collected from the entrance of an old adit and polished sections of these (Appendix 6) reveal that together with free gold they contain common pyrite and arsenopyrite in quartz gangue. Early galena and sphalerite are also present. Boulangerite and gold are later crystallisation phases and bournonite may occur as late-stage veinlets. Free gold was also observed in quartz vein float associated with arsenopyrite and cutting a dioritic rock.

Clarke concludes that samples from the adit indicate the presence of polymetallic Cu-Pb-Zn-As-Ag-Au mineralisation which may be associated with an intermediate intrusion. Scheelite, which is common in panned concentrates, may be the result of contact metasomatic effects. The association of gold with antimony in the Ayllón area and the gold to silver ratio of approximately 2:1 indicate that the occurrence may be different from the polymetallic mineralisation at Peggy Mine where gold values are consistently low and silver/gold rates considerably higher.

The high gold assays of up to 635 ppm obtained for sample MC-25B from the adit entrance, and the presence upstream of free gold and arsenopyrite quartz float (MC-27A) suggests the Ayllón area may have considerable hard rock potential and that further more detailed studies are warranted.

Follow-up studies in the Espiritu Playa and Burro Playa-Principal- Río San Francisco areas (Appendix 4) were disappointing in terms of observed mineralisation, although gold was panned.

It appears from the Project studies that the Baños front-related gold belt, the Collay-Shincata belt of Litherland (1988), is a reality and is related, in the main, to high-level Cenozoic intrusives.

4.6 The Tres Lagunas granite suite: tin-tungsten potential?

4.6.1 Introduction

The Tres Lagunas granite suite does not appear to be a typical Andean I-type association but shows features of S-type granites (see 2.3.2), which elsewhere in the world may be associated with tin-tungsten deposits. A Tres Lagunas “tin-tungsten belt” was proposed in Litherland (1988) based on sporadic occurrences believed to be associated with the granites, and the area was studied in more detail by Clarke and Viteri (Appendix 4).

4.6.2 Results of Clarke and Viteri (Appendix 4) (Map 8)

- (a) In the Peggy Mine area south of Sigsig, cassiterite is common in Quebrada Reote (see Map 13 in Litherland, 1988), and a few grains together with scheelite were also present in a panned concentrate taken from the Río Santa Bárbara near to Peggy Mine. Samples from this mine contain stannite. Although the mine host rocks belong to the Tres Lagunas suite it is considered that these Sn minerals, together with tourmaline, relate to the late porphyries. Overall, the Sn-W-Ag values are reminiscent of Peruvian-Bolivian deposits.
- (b) In the Burro Playa-Principal-Río San Francisco area there are several fault-bounded lenses of Tres Lagunas granite, but no cassiterite was present in panned concentrates and only minor amounts of scheelite were recorded.
- (c) At Loma del Inca, east of the Las Aradas; at the Malacatos basin north of Malacatos; and at outcrops of granite and late pegmatite veins exposed on the new road from Loja to San Lucas, NW of Loja, no cassiterite was present in the panned samples, although minor amounts of scheelite were noted in streams draining the northern edge of the Malacatos basin. Maximum values of 23 ppm Sn and 32 ppm W were obtained from rock samples from the Loma del Inca area.
- (d) At the Espiritu Playa area to the SE of Gima greisens are present to the west of Moriré; but no cassiterite or scheelite was noted in the panned concentrates collected from this zone. However, a single “greisen” sample gave a value of 63 ppm Sn.

- (e) To the east of Saraguro previous work by UNDP (1972) had noted the presence of cassiterite and scheelite in panned concentrates and a sample collected from the Río Pichanal (GR 064 984) contained “common” cassiterite and “considerable” amounts of scheelite. However, the relationship of this mineralisation to the Tres Lagunas batholith which lies immediately to the east remains to be established.
- (f) A single sample of tourmalised Tres Lagunas granite from the Río Macuchi, which is located ca. 9 km to the ESE of Cochapata, was analysed, but was found not to contain significant values of either tin or tungsten (Appendix 1, Table 3, No. FV-848).

4.6.3 Conclusions

Although the presence of tin at Peggy Mine and the cassiterite/scheelite anomaly to the east of Saraguro have been confirmed, elsewhere in the Tres Lagunas suite only scheelite has been recorded and this mineral may be related to the presence of an as yet unmapped “I-type” granite. The value of 63 ppm tin in a single greisen sample from the Espiritu Playa area is of interest, but at present can only be regarded as an isolated occurrence.

In addition to the above evidence, whole-rock analyses of the granites (Appendix 4), although small in number, suggest that they are not a highly differentiated “S-type” suite and do not really possess the extreme geochemical characteristics which are shown by some tin-bearing granites elsewhere in the world. Therefore, on the present evidence the Tres Lagunas suite should not be considered as localising a potential tin/tungsten province, although it may be significant that the two tin occurrences in Ecuador are geographically related to the suite.

The “Tres Lagunas” rocks in the north contain a garnet-rich granoblastic unit (Map 1), which studies actually in progress indicate the following modes: garnet (10-30%), altered feldspar (5-40%) and quartz (30-45%). Thus, the rocks may represent peraluminous differentiates of the Tres Lagunas suite and/or pelitic contamination. A sample collected near Oyacachi contains ?cassiterite in thin section and a float sample from the Río Chalpi de Papallacta, ?wolframite. Furthermore, this latter river shows a 19 ppm Ag fluvial anomaly. Chemical analyses of these rocks now in progress should indicate any Sn-W-Ag potential and corresponding mineral target lithology within the Tres Lagunas suite.

4.7 The Zamora-Abitagua continental arc: gold potential

4.7.1 Introduction

The Zamora gold mining district was described under the sub-Andean gold belt in Litherland (1988). Four hard rock gold mining areas within this belt: Nambija, Piuntza, Chinapintza and Los Planes were visited and sampled by Clarke and Viteri during 1988 (Map 8). The following summary is based largely on their findings (Appendix 4). Mineralogical details of individual samples collected and referred to in Clarke’s report are given in Appendix 6.

4.7.2 The Nambija mines

The mineralisation is hosted in skarn rocks and it is significant that at least one skarn sample (No. 64E, Appendix 6) is derived from an andesitic tuff rather than a carbonate. Gold mineralisation post-dates the skarnification of the host rocks and is accompanied by quartz, pink feldspar (adularia) $\pm$ calcite $\pm$ pyrite. Clarke considers that the protolith may have consisted of a calcareous volcanoclastic sequence and intermediate sub-volcanic bodies possibly in an arc-fringing reef environment. The Nambija gold appears to have low silver ratios which contrast with samples analysed from elsewhere in the sub-Andean gold belt.

4.7.3 The Piuntza and Chinapintza areas

Unlike Nambija and Guaysimi (Map 8), where calc-silicate skarn rocks are widespread, Piuntza and Chinapintza are associated with late feldspar porphyry intrusives and gold mineralisation of probable epithermal origin occurs in veins and breccias.

At Piuntza volcanic and volcanoclastic rocks are dominant and small areas of porphyry are currently being unroofed. In the Chinapintza area the relief is such that an apparent zonation can be seen from high-level stockworks down to larger, sulphide-bearing veins which at depth are related to a quartz porphyry body that is exposed in some of the mine adits.

4.7.4 The Los Planes-La Cruz area

The Los Planes area consists of an irregular series of quartz veins and stockworks which contain disseminated gold and auriferous pyrite and are hosted by andesitic-dacitic lavas and pyroclastics. Regionally, the mineralisation is associated with calc-alkaline volcanics with a batholith substrate.

This area has been explored by a mining company. However, it appears that the relatively low gold values and small tonnage of the deposits do not warrant further large-scale investment at present.

In addition to the above, propylitized samples were collected from the Palanda area and also, further to the south, along the track from Chito to La Cruz which leads to Los Planes. One of these samples, which consisted of a small copper vein cutting the granodiorite of the Zamora-Río Mayo batholith assayed 1.12 ppm Au but otherwise no significant values were recorded.

4.7.5 Conclusions

The general geographical association between the Zamora-Río Mayo batholith and associated volcanics and the sub-Andean gold belt seems to be established but the actual age of the gold mineralisation remains in doubt. As noted in 2.3.10, the bulk of the batholith is considered to be Jurassic to possibly lower Cretaceous in age and it is possible (though not proven) that the mineralisation in the Nambija (and Guaysimi) area is also of this age. However, in Chinapintza and Piuntza the gold mineralisation is demonstrably related to small-scale, high-level, porphyry stocks which may post-date the main Jurassic volcano-plutonic event. According to Ing. E. Salazar (personal communication) primary mineralisation has now been confirmed within the Lower Cretaceous Hollín Formation to the east of Zamora and this observation suggests either an upper Cretaceous or possibly Tertiary age for at least some of the gold mineralisation in the sub-Andean belt. Such Cenozoic volcanic activity would be geotectonically analogous to the recent activity further north manifested at Reventador, Sumaco and Pan de Azucar volcanos.

The Jurassic continental arc can be traced from Zamora north to the Abitagua-Misahuallí plutonic-volcanic pair, where gold mineralisation is indicated (Litherland, 1988), but has yet to be established.

5. CONCLUSIONS AND FUTURE WORK

This report summarizes the results of another year's work during which the Project has further defined the geology of the Cordillera Real, discovered new mineral occurrences and geochemical anomalies, and enhanced the database required for future mining investment.

Many names appear on the title page of this report and, whatever their field of study, all have contributed to the further understanding of a cordillera, which is geographically "Andean" but which shows a whole range of uncharacteristic features such as "Alpine"-type ophiolite belts, "Himalayan"-type tectonics, "Hercynian"-type granites and possible "Alaskan"-type ultramafic pipes. Moreover, the mineral potential cannot be regarded as simply related to processes of Nazca plate subduction. Instead, this process was superimposed on a collision framework involving oceanic crust, island arcs and continental plates and arcs, each element carrying its own mineral signature.

In the northern part of the cordillera, a country of poor access, the efforts of Bermúdez, Pozo and Litherland are being rewarded: a new island arc sequence is being discovered, containing a skarn belt at least 150 km long. It is believed that the main mineral potential lies in this the Azafrán "island arc" belt and mapping in 1989-1990 between the Río Salado and the Colombian border, should delimit its northern continuation and define the plutonic, volcanic and sedimentary elements and complex imbricate thrust tectonics (Figure 2); accompanied by visits to the alluvial goldfields of Cofanes and Chalupas.

In the south the efforts of Viteri, Aspden and Clarke have been rewarded in the definition both of new geological elements, including the Tres Lagunas granite, and also metallogenic models for the two gold belts. Viteri and Aspden will extend their studies north of the Río Paute as far as the Río Pastaza and attempt to link the geology of the north and south by identifying units such as the Tres Lagunas granite and the Azafrán "island arc" and accompanying Llanganates skarns.

The period 1989-1990 is the fourth and last year of Project reconnaissance studies and next year a 1986-1990 Summary Report will be presented along with the 1989-1990 Annual Report.

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APPENDIX 1

Chemical rock analysis and sample data

Table 1. Chemical analyses of rocks samples from regional ultramafic - mafic complexes

COMPLEX	SAMPLE	LITHOLOGY	Mo (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppm)	Ni (ppm)	Co (ppm)	Mn (ppm)	Fe (%)	As (ppm)	U (ppm)	Th (ppm)	Sr (ppm)	Cd (ppm)	Sb (ppm)	Bi (ppm)	V (ppm)	Ca (%)	P (%)	La (ppm)	Cr (ppm)	Mg (%)	Ba (ppm)	Ti (%)	B (ppm)	Al (%)	Na (%)	K (%)	W (ppm)	Au (ppb)
Peltetec belt (Peltetec)	RB-59-A	Serpentinite	1	6	2	30	0.1	388	89	650	8.01	6	5	1	2	1	2	2	74	0.05	0.001	2	810	19.05	1	0.01	17	5.86	0.01	0.01	4	1
	RB-59-B	Gabbro	1	42	2	27	0.1	173	23	368	2.95	2	5	1	16	1	2	2	34	1.84	0.001	2	305	3.73	12	0.02	6	3.02	0.03	0.03	3	1
	RB-59-D	Picrite	1	40	2	90	0.1	170	28	328	2.92	2	5	1	8	1	2	2	22	1.11	0.007	2	188	3.84	8	0.03	7	2.42	0.02	0.01	1	1
	RB-59-H	Brucite-periclase rock	1	9	2	62	0.1	175	38	2359	4.85	3	5	1	2	1	2	2	161	0.37	0.004	2	830	16.83	1	0.06	25	5.12	0.02	0.01	5	1
	RB-60-A	Basalt? breccia	1	62	2	26	0.1	28	12	380	1.40	2	5	1	57	1	2	2	42	6.79	0.018	2	56	0.75	7	0.22	8	0.93	0.03	0.01	1	5
Peltetec belt (Penipe)	RB-209-B	Hornblendite	1	77	2	20	0.1	189	21	248	1.83	2	5	1	7	1	2	2	23	0.85	0.007	2	91	3.05	5	0.07	4	1.64	0.07	0.01	1	1
	RB-209-G	Serpentinite	1	15	2	101	0.1	941	46	500	3.10	151	5	1	11	1	2	2	15	0.59	0.002	2	767	17.47	1	0.01	24	0.28	0.01	0.01	1	1
Peltetec belt (Huangualá)	RB-87-G	Serpentinite	1	28	2	18	0.1	1675	80	411	5.00	3	5	1	3	1	2	3	48	0.03	0.005	2	1092	30.07	4	0.01	102	0.40	0.04	0.01	1	1
Soledad belt (Río Mulatos)	RB-261	Serpentinite	1	8	65	117	0.4	483	20	309	1.68	82	5	1	1	1	6	8	9	0.21	0.004	2	814	11.28	3	0.01	4	0.28	0.01	0.01	1	10
Soledad belt (El Triunfo)	RB-296-A	Serpentinite	1	16	6	26	0.1	1086	54	302	2.76	11	5	1	7	1	2	3	21	0.30	0.003	2	1444	28.01	28	0.01	9	0.33	0.01	0.01	1	7
Soledad belt (Soledad)	RB-342	Serpentinite	1	11	2	12	0.1	1806	76	285	3.77	2	5	1	3	1	2	3	15	0.04	0.002	2	1308	17.99	45	0.01	9	0.17	0.01	0.01	1	9
Urcucoca belt	RB-353-F	Serpentinite	1	28	3	27	0.1	867	64	368	4.07	5	5	1	4	1	2	2	27	0.39	0.002	2	1593	16.63	2	0.01	9	0.76	0.01	0.01	2	1
	MP-518-B	Serpentinite	27	42	8	366	0.1	1838	98	1440	5.48	6	5	1	23	1	2	3	28	1.13	0.001	2	4079	11.59	6	0.01	14	0.56	0.01	0.01	1	8
Río Guachalá	RB-1-G	Serpentinite	1	5	2	15	0.1	1167	54	549	6.00	8	5	1	6	1	2	3	18	0.18	0.004	2	1292	21.42	6	0.01	21	0.17	0.01	0.01	1	1
Palenque belt (Pasaje)	FV-285-D	Serpentinite	1	34	2	19	0.1	1047	60	567	3.41	454	5	1	30	1	7	2	23	1.42	0.003	2	683	11.74	12	0.01	14	0.60	0.01	0.01	1	39
	FV-285-P	Basalt	1	46	3	25	0.3	70	12	341	2.68	5	5	1	21	1	2	2	45	1.42	0.060	2	60	1.39	101	0.21	6	1.31	0.16	0.09	1	3
	FV-285-Q	Serpentinite	1	17	2	22	0.1	1612	75	658	4.41	5	5	1	1	1	2	2	3	0.07	0.003	2	108	29.48	3	0.01	5	0.03	0.01	0.01	1	1
El Toro (Raspas)	FV-291-A	Serpentinite	1	10	2	27	0.1	1303	63	656	3.72	5	5	1	1	1	2	2	14	0.15	0.002	2	840	19.59	1	0.01	10	0.20	0.01	0.01	1	1
Zumba	FV-469-A	Gabbro	1	423	5	71	0.4	50	14	412	3.86	5	5	2	106	1	2	2	129	1.78	0.076	9	41	1.44	58	0.18	5	2.58	0.20	0.03	2	1
	FV-469-B	Serpentinite	1	14	6	35	0.1	1176	62	753	4.85	54	5	1	3	1	2	2	11	0.18	0.004	2	543	29.38	7	0.01	34	0.23	0.01	0.01	2	1
	FV-470-B	Serpentinite	1	15	3	34	0.1	2061	94	714	4.78	51	5	1	1	1	2	2	14	0.02	0.003	2	953	29.56	11	0.01	34	0.16	0.01	0.01	1	1
	FV-470-C	Olivine pyroxenite	1	6	3	94	0.1	1138	52	764	2.55	70	5	1	3	1	3	2	7	0.13	0.003	2	282	11.17	6	0.01	32	0.11	0.01	0.01	1	13
Tampanchi	RB-247-C	Hornblendite	1	20	2	4	0.1	50	6	104	0.58	2	5	1	18	1	2	2	10	1.03	0.002	2	32	0.34	30	0.04	8	0.85	0.01	0.01	1	1
	RB-247-G	Pyroxenite	1	524	2	25	0.2	108	31	409	4.03	4	5	1	9	1	2	2	72	0.71	0.005	2	123	3.70	23	0.05	2	0.48	0.04	0.01	1	176
	RB-247-L	Gabbro	1	200	2	14	0.1	29	19	263	2.04	2	5	1	49	1	2	2	69	1.26	0.023	2	31	1.29	24	0.10	3	1.20	0.07	0.05	1	2

ANALYSES BY ACME LABORATORIES, VANCOUVER

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DATA OF ANALYSED SAMPLES (TABLE 1)

RB-59-A: Pungalá-Alao Road (7716-97946), serpentinite block from the Peltetec division ravine.

RB-59-B; RB-59-D; RB-59-H; RB-60-A: Pungalá-Alao Road (7716-97946), outcrops.

RB-209-B: Penipe-Río Blanco Road (7750-98253), hornblendite outcrop.

RB-209-G: Penipe-Río Blanco Road (7750-98253), outcropping serpentinite, Peltetec division.

RB-87-G: Irrigation canal, Huargualla Valley (7713-97923), outcropping serpentinite, Peltetec division.

RB-261: Mulatos River, rolled serpentinite block (Litherland, 1988, Map 7).

RB-296-A: Quebrada Los Incas, junction with the Mayo River (7901-98582), near El Triunfo, serpentinite block.

RB-342: North of the Antisana River (8159-99322), Quebrada Soledad Valley, serpentinite outcrop sample.

RB-353-F: North of the Antisana River, Quebrada Chiriyacu (8195-99306), serpentinite block.

MP-518-B: Cosanga River (8275-99337), serpentinite block.

RB-1-G: Guachalá River, Pan-American highway bridge south of Cayambe, serpentinite block.

FV-285-D: Palenque River, south of Pasaje (El Oro), approx. 1.5 km SE of the quarry, serpentinite outcrop.

FV-285-P: Palenque River, south of Pasaje (El Oro), approx. 4.5 km SE of the quarry, basalt outcrop.

FV-285-Q: Palenque River south of Pasaje (El Oro), approx. 5 km SE of the quarry, serpentinite outcrop.

FV-291-A: Approx. 2 km north of Tahuín (El Oro), serpentinite from the El Toro body quarry.

FV-469-A: Road East of Zumba (Zumba Sheet, 077-630), quarry gabbro.

FV-469-B; FV-470-B; FV-470-C: Road East of Zumba (Zumba Sheet, 077-630), ultrabasic rocks from quarry.

RB-247-C; RB-247-G; RB-247-L: Taday-Huarainac Road (7618-97082), outcrops of the Tampanchi complex.

Table 2. Chemical analyses of skarns and epidotic rocks from the Llanganates belt

COMPLEX	SAMPLE	LITHOLOGY	Mo (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppm)	Ni (ppm)	Co (ppm)	Mn (ppm)	Fe (%)	As (ppm)	U (ppm)	Th (ppm)	Sr (ppm)	Cd (ppm)	Sb (ppm)	Bi (ppm)	V (ppm)	Ca (%)	P (%)	La (ppm)	Cr (ppm)	Mg (%)	Ba (ppm)	Ti (%)	B (ppm)	Al (%)	Na (%)	K (%)	W (ppm)	Au (ppb)
Baeza	RB-43-A	Epidote rock	1	4	8	104	0.2	45	3	460	3.14	4	5	3	79	1	3	3	10	1.80	0.0360	12	15	1.27	7	0.12	6	1.76	0.01	0.01	2	1
Urcucocha field	RB-353-G	Epidote rock	47	13	2	40	0.4	53	2	340	3.70	12	5	3	94	1	5	3	46	1.75	0.043	3	42	1.93	7	0.24	4	2.17	0.02	0.01	3	1
	MP-508-B	Epidote rock	1	49	13	578	0.1	13	5	1604	4.65	8	5	1	99	1	2	2	33	6.32	0.065	7	21	1.27	67	0.18	3	2.49	0.01	0.07	1	16
	MP-514-A	Epidote rock	5092	9	19	129	0.3	12	12	493	1.47	9	5	1	80	1	2	2	334	4.42	0.041	2	35	0.15	3	0.40	2	0.86	0.01	0.02	1	32
	MP-514-D	Epidote rock	3383	8	20	327	0.3	16	23	461	1.83	12	5	1	81	1	2	2	289	4.11	0.092	2	41	0.12	6	0.44	4	0.85	0.01	0.01	1	26
	MP-514-G	Epidote rock	70	5	11	246	0.1	13	6	471	1.36	5	5	1	84	1	2	2	66	3.75	0.015	4	15	0.17	10	0.13	4	0.94	0.01	0.01	1	43
Río Oyacachi	MP-472-F	Skarn	23	114	17	297	0.4	22	14	1056	7.88	18	5	3	30	1	13	14	61	1.58	0.115	5	49	0.50	58	0.11	3	1.92	0.15	0.10	5	3
	MP-480-E	Skarn	23	13	6	16	0.2	14	7	3918	2.70	17	5	2	35	1	6	2	61	9.55	0.094	4	31	0.14	9	0.05	2	1.85	0.01	0.01	5	1
Río Quijos	MP-494-G	Skarn	3	9	12	15	0.3	6	7	1521	9.15	25	5	2	6	2	2	2	12	14.67	0.108	3	20	0.03	5	0.03	2	1.32	0.01	0.01	8	1
	MP-494-J	Skarn	2	6	22	41	0.4	8	5	599	6.95	10	5	1	38	1	8	2	19	6.84	0.067	2	8	0.09	6	0.01	2	0.57	0.01	0.01	3	24
	MP-494-K	Skarn	15	10	6	10	0.4	46	236	93	8.74	78	5	3	34	1	2	2	7	1.76	0.346	9	19	0.02	3	0.06	4	0.41	0.01	0.01	7	7
	MP-494-P	Skarn	2	7	30	45	0.3	8	7	715	7.02	8	5	1	66	1	6	2	19	7.71	0.035	2	7	0.14	13	0.01	2	1.05	0.01	0.01	3	1
	MP-494-Q	Skarn	2	12	30	21	0.4	3	8	1130	8.82	15	5	2	45	1	3	5	22	11.91	0.275	2	24	0.09	3	0.04	2	1.25	0.01	0.01	8	4

ANALYSES BY ACME LABORATORIES, VANCOUVER

COURTESY OF B. P. MINERALS INTERNATIONAL, QUITO

DATA OF ANALYSED SAMPLES (TABLE 2)

RB-43-A: Quijos River, 1.5 km ENE of Baeza (8445-99493), rolled block of epidote rock.

RB-353-G: North of the Antisana River, Quebrada Chiriyacu (8195-99306), rolled block.

MP-508-B: Headwaters of the Quebrada Chiriyacu (8216-99299), outcrop.

MP-514-A; MP-514-D; MP-514-G: Urcucocha Hill (8227-99298), outcrop samples.

MP-472-F: Chalpi River (1700-99721), near the Oyacachi River, rolled block.

MP-480-E: Oyacachi River (1786-99729), rolled block.

MP-494-G; MP-494-J; MP-494-K; MP-494-P; MP-494-Q: Quijos River (8372-99520), above the confluence with the Papallacta River, rolled blocks.

Table 3. Chemical analyses of mineralised rocks samples

ZONE	SAMPLE	Mo (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppm)	Ni (ppm)	Co (ppm)	Mn (ppm)	Fe (%)	As (ppm)	U (ppm)	Th (ppm)	Sr (ppm)	Cd (ppm)	Sb (ppm)	Bi (ppm)	V (ppm)	Ca (%)	P (%)	La (ppm)	Cr (ppm)	Mg (%)	Ba (ppm)	Ti (%)	B (ppm)	Al (%)	Na (%)	K (%)	W (ppm)	Au (ppb)
La Florida	CR-FV-372	59	16	54	319	0.5	53	6	30	8.88	214	5	1	3	1	3	2	6	0.02	0.096	2	3	0.02	10	0.01	4	0.11	0.02	0.15	1	230
Quebrada Afiladeras	CR-FV-462	1	46	2	134	0.1	3	16	1415	5.44	8	5	1	231	1	2	2	85	2.62	0.097	2	3	2.04	29	0.08	5	3.78	0.26	0.03	3	1
	CR-FV-463	1	1	2	23	0.1	1	2	228	1.34	2	5	5	43	1	2	2	19	0.39	0.044	21	1	0.05	60	0.01	2	0.94	0.05	0.14	1	1
Río Tintas	CR-FV-519	1	7189	8	122	6.9	28	175	885	11.15	135	5	2	4	2	4	2	23	0.11	0.004	6	16	1.74	5	0.06	3	2.31	0.03	0.01	2	14
Río Collay	CR-FV-380-B	3	7	19	13	1.1	2	1	59	0.78	6	5	1	33	1	2	2	10	0.09	0.014	4	5	0.05	13	0.06	2	0.97	0.01	0.01	1	1
	A-208-R	1	37	26	125	0.4	24	12	27	2.38	4	5	22	13	7	2	2	12	0.31	0.074	29	12	0.65	48	0.07	4	1.04	0.01	0.12	1	1
Río Dominguillo	A-212-R	1	367	15	560	0.6	7	11	640	3.85	7	5	1	13	2	2	3	6	0.67	0.050	6	3	0.42	26	0.01	11	0.41	0.01	0.23	1	1
	A-213-R	1	23	15	5	0.5	4	2	18	0.89	22	5	1	1	1	2	2	1	0.01	0.002	4	2	0.01	11	0.01	8	0.11	0.01	0.06	1	11
Río Culebrillas	A-233-R	1	10	2	70	0.1	2	4	567	2.39	2	5	2	32	1	2	2	12	0.20	0.031	9	2	0.27	16	0.01	10	0.28	0.02	0.02	1	1
Río Burra Playa	A-237-R	3	268	5	142	0.5	8	8	658	5.66	13	5	1	3	1	2	2	6	0.02	0.002	2	3	0.01	21	0.01	2	0.03	0.01	0.01	1	3
Batolito Portachuela	CR-FV-820-Q	3	77	39	79	0.2	8	31	1317	9.48	21	5	4	6	1	6	2	64	0.03	0.055	24	14	1.30	108	0.04	2	5.46	0.01	0.11	4	3
	CR-FV-821-Q	2	2873	187	843	49.0	7	7	27	18.17	1013	5	1	3	3	402	29	9	0.02	0.002	3	4	0.01	6	0.01	2	0.21	0.01	0.11	1	480
	CR-FV-823-Q	17	996	1086	915	10.6	3	6	234	9.03	239	5	4	3	1	53	12	21	0.02	0.056	11	3	0.02	21	0.01	2	0.43	0.01	0.14	1	106
Río Isimanchi	CR-FV-827-Q	5	38	14	15	0.2	6	3	42	2.33	10	5	12	2	1	5	2	1	0.01	0.003	12	5	0.02	22	0.01	2	0.31	0.01	0.15	1	5
Río Vergel	CR-FV-838-Q	3	109	13	29	0.1	9	15	296	5.08	23	5	1	5	1	1	2	15	0.22	0.073	8	8	0.56	32	0.01	4	0.90	0.01	0.26	2	7
Laguna Arrebatada	CR-FV-665	4	16	14	43	0.1	11	4	405	1.90	9	5	4	8	1	3	2	9	0.16	0.020	10	11	0.21	24	0.03	5	0.61	0.04	0.14	2	2
Río Macuchi	FV-848	2	16	24	61	0.1	6	2	63	1.28	15	5	1	4	1	2	2	1	0.02	0.008	2	5	0.01	20	0.01	9	0.34	0.02	0.09	1	82
Quebrada Nancaroyacu	MP-506-B	1	9	19	453	0.1	104	7	228	1.13	8	5	1	11	1	2	3	5	0.69	0.001	2	127	1.67	29	0.01	4	1.97	0.01	0.10	2	46
Río Cosanga	MP-530-A	5	232	32	154	0.6	24	42	4384	29.22	19	5	1	17	1	2	2	17	0.38	0.125	2	10	0.87	39	0.01	2	1.04	0.01	0.01	1	2
	MP-530-B	5	16	2	20	0.1	8	17	96	0.65	17	5	1	3	1	2	2	2	0.03	0.003	2	6	0.02	1	0.01	2	0.06	0.01	0.01	1	1

ANALYSES BY ACME LABORATORIES, VANCOUVER

COURTESY OF B. P. MINERALS INTERNATIONAL, QUITO

DATA OF ANALYSED SAMPLES (TABLE 3)

CR-FV-372: West of La Florida (Gima-Nueva Tarqui), volcanic rocks with pyrite (Chapiza Formation?).

CR-FV-462; CR-FV-463: Quebrada Afiladeras (Zumba Sheet, 210-612), volcanoclastic rocks (tuffs?).

CR-FV-519: Tintas River (Cordova Sheet, 708-816), rolled block, recent felsite.

CR-FV-380-B: Collay River (Cordova Sheet, 617-831), rolled block of silicified volcanic rock with pyrite.

A-208-R: Collay River (Cordova Sheet, 612-825), quartz veinlets with sulphides.

A-212-R; A-213-R: Domingullo River (Guachapala Sheet, 685-915), felsites with pyrite, contact zone with Tertiary porphyry body (Cerro Negro).

A-233-R: Culebrillas River (Cordova Sheet, 599-740), felsite with pyrite.

A-237-R: Burro Playa River (Principal Sheet, 574-628), rolled block of altered felsite with pyrite.

CR-FV-820-Q; CR-FV-821-Q; CR-FV-823-Q: Amaluza-Zumba Road (Laguna Cox Sheet, 784-720), from sulphide-rich drag zones in the Portachuela batholith.

CR-FV-827-Q: Isimanchi River (Laguna Cox Sheet, 6807-94709), pyrite-rich rolled felsite block.

CR-FV-838-Q: Vergel River upstream (Map 11), rolled quartz and pyrite rock.

CR-FV-665: Laguna Arrebatada (Amaluza Sheet, 884-904), porphyry with pyrite.

FV-848: Macuchi River (Nabón Sheet, 7213-96224), rolled quartz block with pegmatitic tourmaline.

MP-506-B: Quebrada Ñancaroyacu (8193-99306), rolled block of rock with fuchsite.

MP-530-A: Cosanga River (1738-99270), talus block of the Napo Formation with pyrite.

MP-530-B: Cosanga River (1738-99276), rolled block of coal rock.

Table 4. Trace element analysis of rocks

ZONE	SAMPLE	Mo (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppm)	Ni (ppm)	Co (ppm)	Mn (ppm)	Fe (%)	As (ppm)	V (ppm)	Cr (ppm)	Ti (ppm)	W (ppm)	Au (ppm)	Sn (ppm)
Peltetec	RB-209-B		46	Nd	146		218	20	240	1.54							
	RB-209-E		32	Nd	32		223	10	225	1.09							
	RB-209-G		13	20	31		1000	65	650	3.45							
Tampanchi	RB-247-A		17	10	49		106	Nd	316	1.06							
Palenque	FV-285-Q		14	50	38		2200	90	980	4.84							
	FV-285		21	25	71		1550	85	740	4.52							
El Toro	FV-291-A		11	40	46		1750	90	990	4.47							
Quebrada Los Incas	RB-296-B		19	50	69	6	1780	75		5.43		52	1900				
Cerro Hermoso	RB-313-A		20	55	268	1	850	30		15.99		232	146				
	RB-326-C		390	20	26	3	344	960		27.33		79	40				
Río Antisana	RB-342		140	Nd	128	1	3560	140		8.76		34	3900				
	RB-353-A		30	20	126	3	549	30		9.60		191	174				
	RB-353-E		100	Nd	194	Nd	1680	100		6.50		34	1600				
	RB-353-G		40	Nd	96	1	1080	40		8.22		214	219				
	RB-353-I		60	Nd	840	Nd	166	60		12.60		379	82				
Río Oyacachi	MP-466-B		62	42	114	Nd	32	96	302				29			0.10	
	MP-475		1000	34	54	Nd	96	278	438				4			0.35	
	MP-488		30	48	100	4	110	110	3200				63			Nd	
Río Chalpi	MP-472-M		14	68	66	Nd	70	42	800				43			Nd	
Río Quijos	MP-494-A		10	64	58	Nd	110	106	5600				64			0.35	
	MP-494-D		28	78	42	Nd	152	1100	756				74			0.30	
Río Antisana	MP-502	Nd	9	44	69	Nd	622	45	375	3.02		12	72	45	11	Nd	
	MP-503	17	12	109	86	Nd	230	20	2000	3.39		34	86	693	8	Nd	
Cerro Urcucocha	MP-514-C	5	14	173	54	3	185	27	1200	7.80		460	165	3300	18	Nd	
	MP-514-D	2000	24	217	54	8	424	60	802	8.13		1900	493	19600	9	Nd	
Río Cosanga	MP-519	123	15	47	114	Nd	847	43	382	2.63		36	315	370	23	Nd	
	MP-520-B	Nd	7	41	204	Nd	636	51	1100	3.46		17	315	51	6	Nd	
Río Espíritu Playa	FV-716														31	Nd	Nd
Río Macuchi	FV-848														19		Nd

Nd = Not detected

ANALYSES BY INEMIN LABORATORIES, CHILLOGALLO

DATA OF ANALYSED SAMPLES (TABLE 4)

RB-209-B; RB-209-E: Penipe-Río Blanco Road (7750-98233), hornblendite outcrops, Peltetec division.

RB-209-G: As above, serpentinite outcrop.

RB-247-A: Taday-Huarainac Road (7618-97082). Hornblende-asbestos rock from the Tampanchi ultramafic complex.

FV-285-Q: Palenque River, south of Pasaje (El Oro), approx. 5 km SE of the quarry, serpentinite outcrop.

FV-285: Palenque River, south of Pasaje (El Oro), serpentinite from the quarry.

FV-291-A: Quarry, approx. 2 km north of Tahuín (El Oro), serpentinite from the El Toro body.

RB-296-B: Quebrada Los Incas, junction with the Mayo River (7901-98582), serpentinite block.

RB-313-A: Cerro Hermoso (8016-98638), outcrop of garnet rock with sulphides.

RB-326-C: Cerro Hermoso (8012-98643), schist with sulphides from an old workings site.

RB-342: North of the Antisana River (8159-99322), Quebrada Soledad Valley, serpentinite outcrop sample.

RB-353-A: North of the Antisana River, Quebrada Chiriyacu (8195-99306), serpentinite block sample.

RB-353-E: As above, mafic metalava block with sulphides.

RB-353-G: As above, epidote rock block from the Urcucocha skarn.

RB-353-I: As above, mineralized mafic metalava block.

MP-466-B: Oyacachi River, bridle path, (8336-9975) mineralized feldspar rock block.

MP-475: Oyacachi River (1763-99733), Río Cedro orthogneiss with minor Cu mineralization.

MP-488: Oyacachi River (1819-99700), rolled block, banded green metavolcanic rock with sulphides.

MP-472-M: Chalpi River (1700-99721), near the Oyacachi River, graphite rock block with sulphides.

MP-494-A; MP-494-D: Quijos River (8372-99520), rolled blocks of calc-magnesian skarn.

MP-502: North of the Antisana River (8159-99322), Quebrada Soledad Valley, serpentinite outcrop sample.

MP-503: North of the Antisana River (8174-99324), weathered Tres Lagunas granite outcrop with mineralization.

MP-514-C; MP-514-D: Urcucocha Hill (8227-99298), samples of epidote rock (skarn).

MP-519: Cosanga River (8275-99336), rolled serpentinite block with asbestos vein.

MP-520-B: Cosanga River (8313-99336), rolled quartzite block with sulphides.

FV-716: Espiritu Playa River (Map 14), Tertiary granite with alterations and presence of pyrite.

FV-848: Macuchi River (7213-96224), rolled quartz block with pegmatitic tourmaline.

APPENDIX 2

Geochemical analysis of stream sediments

Third Annual Report (1988-1989)

INSTITUTO ECUATORIANO DE MINERÍA DEPARTAMENTO DE LABORATORIOS CHEMICAL ANALYSIS REPORT

LAB N°: 3915 DELIVERY: Ing. Iván Endara DATE: 88-12-27
N° of SAMPLES: Seven Jefe de Laboratorios
REQUESTED BY: Ing. Miguel Pozo RECEPTION: Ing. Marco Marín DATE: 88-12-27
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Napo; Oyacachi- El Chaco (Map 3)

DETERMINATIONS

SAMPLE CODE	Mn (ppm)	Zn (ppm)	Pb (ppm)	Co (ppm)	Cu (ppm)	Ag (ppm)	Ni (ppm)	As (ppm)
F-93	3200	108	62	22	54	Nd	82	198
F-95	664	90	30	26	56	Nd	32	105
F-96	3800	120	26	44	46	Nd	70	150
F-99	1100	98	34	48	40	Nd	46	125
F-98	848	110	42	34	52	Nd	98	115
F-100	884	106	24	52	52	Nd	108	150
F-101	832	124	52	36	40	Nd	70	98

ASSAYED BY: Determinaciones Analíticas

MARIANA LÓPEZ
Jefe de Determinaciones Analíticas

Third Annual Report (1988-1989)

INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 3999 DELIVERY: Ing. Iván Endara DATE: 89-04-24
N° of SAMPLES: Seven Jefe de Laboratorios
REQUESTED BY: Ing. Miguel Pozo RECEPTION: Ing. Marco Marín DATE: 89-05-03
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Napo-Papallacta; Río Salado-Río Diviso (Map 7)

DETERMINATIONS

SAMPLE CODE	Zn (ppm)	Pb (ppm)	Co (ppm)	Cu (ppm)	Ag (ppm)	Ni (ppm)	Cr (ppm)	Mo (ppm)	As (ppm)
112F-3	156	108	28	28	1	62	54	14	36
113F-3	140	119	28	53	Nd	43	28	Nd	40
115F-4	127	125	35	52	Nd	76	81	Nd	28
116F-4	159	146	43	69	1	79	82	Nd	22
117F-4	102	110	30	52	Nd	46	29	17	42
119F-4	90	121	31	50	5	53	55	21	44
120F-4	106	149	41	71	4	57	55	22	42

Nd = Not detectable

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.
Jefe de Determinaciones Analíticas

Cordillera Real Geological Research Project

INSTITUTO ECUATORIANO DE MINERÍA

DEPARTAMENTO DE LABORATORIOS

CHEMICAL ANALYSIS REPORT

LAB N°: 3893

DELIVERY: Ing. Iván Endara

DATE: 88-12-01

N° of SAMPLES: Nine

Jefe de Laboratorios

REQUESTED BY: Ing. F. Viteri

RECEPTION: Ing. Marco Marín

DATE: 88-12-01

PROJECT: Cordillera Real

Director de investigación geológica

ORIGIN: 147-152 Palanda-La Canela (Map 11); 226F-V-229F-V Amaluza-Mangira-Palanda (Map 11); 230M-V Río Mayo ca. 1.5 km upstream from the junction with the Isimanchi River (Zumba topographic sheet, 124-652).

DETERMINATIONS

SAMPLE CODE	Zn (ppm)	Pb (ppm)	Cu (ppm)	Ag (ppm)	Fe (%)	Co (ppm)	Ni (ppm)	Mn (ppm)
CR-147-F	78	24	12	Nd	8.00	20	60	600
CR-151-F	326	46	120	Nd	19.60	60	100	1900
CR-152-F	106	32	68	Nd	9.80	40	80	980
CR-148-F	70	50	8	Nd	8.80	20	80	860
A-229-F-V	108	42	22	Nd	3.00	20	100	940
A-226-F-V	62	28	6	Nd	1.40	20	60	1000
A-228-F-V	100	12	18	Nd	3.40	20	80	1000
A-227-F-V	114	40	16	Nd	6.20	20	80	1100
A-230-M-V	124	46	12	Nd	11.00	80	180	1400

Nd = Not detectable, less than 2 ppm Ag

ASSAYED BY: Determinaciones Analíticas

MARIANA LÓPEZ

Jefe de Determinaciones Analíticas

Third Annual Report (1988-1989)

INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 3893 DELIVERY: Ing. Iván Endara DATE: 89-02-22
N° of SAMPLES: Nine Jefe de Laboratorios
REQUESTED BY: Ing. F. Viteri RECEPTION: Ing. Marco Marín DATE: 89-02-24
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: 147-152 Palanda-La Canela (Map 11); 226F-V-229F-V Amaluza-Mangira-Palanda (Map 11); 230M-V Río Mayo ca. 1.5 km upstream from the junction with the Isimanchi River (Zumba topographic sheet, 124-652).

DETERMINATIONS

SAMPLE CODE	V (ppm)	Ti (%)	Cr (ppm)
CR-147-F	88	0.14	19
CR-151-F	655	1.04	51
CR-152-F	316	0.44	25
CR-148-F	112	0.16	29
A-229-F-V	72	0.41	39
A-226-F-V	25	0.37	8
A-228-F-V	58	0.49	21
A-227-F-V	130	0.47	26
A-230-M-V	296	0.65	35

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.
Jefe de Determinaciones Analíticas

Cordillera Real Geological Research Project

INSTITUTO ECUATORIANO DE MINERÍA

DEPARTAMENTO DE LABORATORIOS

CHEMICAL ANALYSIS REPORT

LAB N°: 3942 DELIVERY: Ing. Iván Endara DATE: 89-01-04
N° of SAMPLES: Four Jefe de Laboratorios
REQUESTED BY: Ing. F. Viteri RECEPTION: Ing. Marco Marín DATE: 89-01-09
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Morona Santiago; Cochapata-Yacuambí (Map 14)

DETERMINATIONS

SAMPLE CODE	Zn (ppm)	Pb (ppm)	Co (ppm)	Mn (ppm)	Cu (ppm)	Ag (ppm)	Ni (ppm)	Fe (%)	Cr (ppm)	Ca (%)	Al (%)	As (ppm)
A-157-F	13	65	11	552	12	1	9	1.78	22	0.61	1.69	130
A-158-F	22	30	12	371	24	Nd	Nd	1.68	1	0.21	1.00	120
A-160-F	54	82	18	650	18	Nd	Nd	2.61	14	0.55	1.85	115
A-163-F	39	27	11	442	17	Nd	Nd	2.14	Nd	0.11	1.28	110

ASSAYED BY: Determinaciones Analíticas

MARIANA LÓPEZ
Jefe de Determinaciones Analíticas

Third Annual Report (1988-1989)

INSTITUTO ECUATORIANO DE MINERÍA DEPARTAMENTO DE LABORATORIOS CHEMICAL ANALYSIS REPORT

LAB N°: 3942 DELIVERY: Ing. Iván Endara DATE: 89-02-27
N° of SAMPLES: Four Jefe de Laboratorios
REQUESTED BY: Ing. F. Viteri RECEPTION: Ing. Marco Marín DATE: 89-02-28
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Morona Santiago; Cochapata-Yacuambí (Map 14)

DETERMINATIONS

SAMPLE CODE	Mo (ppm)
A-157-F	Nd
A-158-F	Nd
A-160-F	Nd
A-163-F	Nd

Nd = Not detectable, less than 5 ppm Mo

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.
Jefe de Determinaciones Analíticas

INSTITUTO ECUATORIANO DE MINERÍA

DEPARTAMENTO DE LABORATORIOS

CHEMICAL ANALYSIS REPORT

LAB N°: 3735 DELIVERY: Ing. Iván Endara DATE: 88-04-08
 N° of SAMPLES: Fifteen Jefe de Laboratorios
 REQUESTED BY: Ing. F. Viteri RECEPTION: Ing. W. Santamaría DATE: 88-04-12
 PROJECT: Cordillera Real Director de investigación geológica
 ORIGIN: 105-108 Río Santa Bárbara-Mina Peggy (Sigsig) (Litherland, 1988, Map 13); 109 Río Osocachi (NW de Principal); 111-123 Oña-Yacuambí (Litherland 1988, Map 15)

DETERMINATIONS

SAMPLE CODE	Ag (ppm)	Zn (ppm)	Pb (ppm)	Co (ppm)	Mn (ppm)	Cu (ppm)	Ni (ppm)
A-105	1	31	20	Nd	179	8	Nd
A-106	Nd	25	20	Nd	110	9	Nd
A-107	2	111	20	Nd	316	16	Nd
A-108	4	332	320	15	1380	42	Nd
A-109	Nd	184	30	10	371	44	19
A-111	1	79	30	30	585	62	33
A-113	Nd	55	25	20	409	65	9
A-114	Nd	45	20	Nd	322	57	Nd
A-115	Nd	49	20	45	348	44	Nd
A-116	Nd	60	20	25	466	840	Nd
A-117	Nd	50	Nd	30	507	56	Nd
A-118	Nd	105	300	30	575	499	13
A-120	Nd	52	Nd	35	543	45	9
A-121	Nd	64	20	30	870	57	19
A-123	Nd	45	20	40	390	43	18

Nd = Not detectable, less than 10 ppm Pb and Co, 1 ppm Ni and Ag

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.
 Jefe de Determinaciones Analíticas

NOTE: The results for Mo and Cr cannot yet be reported due to the lack of necessary equipment

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INSTITUTO ECUATORIANO DE MINERÍA DEPARTAMENTO DE LABORATORIOS CHEMICAL ANALYSIS REPORT

LAB N°: 3793

DELIVERY: Ing. Iván Endara

DATE: 88-05-08

N° of SAMPLES: Thirty-four

Jefe de Laboratorios

REQUESTED BY: Ing. F. Viteri

RECEPTION: Ing. W. Santamaría

DATE: 88-05-

PROJECT: Cordillera Real

Director de investigación geológica

ORIGIN: 126-138 Gima-La Florida-Nueva Tarqui (Litherland, 1988, Map 14); 200-205 Gima-Chigiinda-Gualaquiza (Map 14); 206-222 Sevilla de Oro-Copal (it includes Río Copal, 206-209) (Map 11); 225 La Merced- Río Arenillas (Map 12)

DETERMINATIONS

SAMPLE CODE	Ag (ppm)	Zn (ppm)	Pb (ppm)	Cu (ppm)	Co (ppm)	Ni (ppm)	As (ppm)
A-88-126	Nd	58	20	10	20	40	39
A-88-127	Nd	60	20	20	Nd	50	50
A-88-128	Nd	85	20	20	20	20	29
A-88-129	Nd	100	50	10	20	30	36
A-88-130	Nd	156	50	40	45	65	52
A-88-131	Nd	135	50	70	65	50	39
A-88-132	Nd	146	50	100	60	55	31
A-88-133	Nd	240	95	190	65	60	60
A-88-134	Nd	219	100	270	100	35	104
A-88-135	Nd	205	90	80	100	90	57
A-88-136	Nd	90	40	40	85	70	21
A-88-137	Nd	82	30	60	80	90	21
A-88-138	Nd	90	10	50	30	50	26
A-88-200	Nd	89	40	20	50	60	18
A-88-201	Nd	60	10	20	30	Nd	18
A-88-202	Nd	90	20	10	30	20	13
A-88-203	2	50	20	20	30	40	29
A-88-204	2	63	30	20	30	30	20
A-88-205	Nd	95	20	30	50	40	48
A-88-206	4	205	60	20	80	50	42
A-88-207-A	Nd	57	10	Nd	10	25	18
A-88-207-D	3	186	70	50	70	50	34
A-88-208	Nd	39	30	Nd	60	35	16
A-88-209	1	36	30	10	40	35	9
A-88-210	Nd	380	40	100	55	40	18
A-88-211	2	137	20	70	40	20	23
A-88-214	Nd	56	Nd	10	25	40	21
A-88-215	3	99	10	30	40	45	13
A-88-216	3	60	10	10	30	40	21
A-88-217	Nd	56	Nd	20	35	40	26
A-88-219	3	54	10	20	50	40	13
A-88-221	Nd	50	20	40	20	30	23
A-88-222	1	149	40	60	80	20	28
A-88-225	3	97	10	20	55	20	16

Nd = Not detectable, less than 1 ppm Ag, 10 ppm Pb, Co, Cu and Ni

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.

Jefe de Determinaciones Analíticas

NOTE: The results for Cr and Mo cannot be reported yet.

INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 3795 DELIVERY: Ing. Iván Endara DATE: 88-05-19
N° of SAMPLES: Nine Jefe de Laboratorios
REQUESTED BY: Ing. F. Viteri RECEPTION: Ing. W. Santamaría DATE: 88-05-20
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Palanda-La Canela-Río Pangura traverse; 224-229 La Merced-Arenillas; 230-236 Maylas-La Merced
(Litherland, 1988, Map 12)

DETERMINATIONS

SAMPLE CODE	Ag (ppm)	Zn (ppm)	Pb (ppm)	Cu (ppm)	Co (ppm)	Ni (ppm)	As (ppm)
A-88-224	Nd	112	20	60	50	50	33
A-88-226	1	117	20	50	30	45	23
A-88-227	1	69	Nd	20	20	30	23
A-88-228	2	70	Nd	50	45	40	38
A-88-229	Nd	74	20	40	40	30	25
A-88-231	Nd	78	20	20	30	30	26
A-88-232	Nd	47	30	Nd	40	35	18
A-88-234	Nd	56	30	Nd	20	20	21
A-88-236	Nd	120	60	90	20	30	30

Nd = Not detectable, less than 1 ppm Ag, 10 ppm Pb and Cu

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.
Jefe de Determinaciones Analíticas

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INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 3795 DELIVERY: Ing. Iván Endara DATE: 89-04-13
N° of SAMPLES: Nine Jefe de Laboratorios
REQUESTED BY: Ing. F. Viteri RECEPTION: Ing. Marco Marín DATE: 89-04-17
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Palanda-La Canela-Río Pangura traverse; 224-229 La Merced-Arenillas; 230-236 Maylas-La Merced
(Litherland, 1988, Map 12)

DETERMINATIONS

SAMPLE CODE	Cr (ppm)	Mo (ppm)
A-88-224	53	13
A-88-226	81	Nd
A-88-227	41	Nd
A-88-228	52	Nd
A-88-229	58	Nd
A-88-231	71	30
A-88-232	50	Nd
A-88-234	39	2
A-88-236	49	3

Nd = Not detectable, less than 1 ppm Mo

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.
Jefe de Determinaciones Analíticas

APPENDIX 3

Work completed on three mineral belts in the Cordillera Real,
Ecuador, during May, June and July 1988

by

M. C. G. Clarke, BSc., PhD, MIMM

BGS

Report No. WC/88/29/R

1. INTRODUCTION

This visit represents a specialised input into the ongoing bilateral Cordillera Real Project, which commenced in 1986 and is due for completion in 1990. The project has made considerable progress in understanding the regional geological framework and it was considered that the various mineral occurrences encountered in the Project area required a more detailed study.

The UK Project Manager, Dr Litherland, requested that this study concentrate on the southern part of the Project Area, that part familiar to Ing. Viteri, as he would be the local counterpart geologist accompanying the writer.

It was also decided that the investigation should concentrate on the mode of occurrence and genesis of Primary mineralisation particularly in the following 3 mineral “belts” (as defined in the Annual Report of the Project for 1987-1988):

(a) Sub-Andean Gold Belt

This is geographically associated with a volcano-plutonic complex in the SE part of the Project area and was known to include the important skarn related Nambija type Primary deposits.

(b) Collay-Shincata Gold Belt

The zone is geographically confined to the western part of the Cordillera Real, essentially between the main Andean watershed and the ‘Baños front’. Within this area are some of the famous ancient alluvial mining areas. No primary sources known.

(c) Tres Lagunas ‘tin-tungsten’ belt

This belt is defined as the result of the recognition of a suite of ‘S-type’ granites associated with a zone of very strong deformation, the Baños front. Both the granites and the deformation are interpreted by the resident Project geologists as being the result of collision tectonics.

This report must be considered as outlining the nature of the work done. Lists of samples collected are appended. Although some broad interpretations are included, they are preliminary ideas only and will be greatly amplified and modified in the full report to be submitted at a later date.

The list of collected samples is included in Tables 1, 2, and 3.

2. OBJECTIVES OF THE VISIT

- (1) To assess the archived material available in Quito.
- (2) To visit representative areas and mineral localities in the three belts, to understand the generalizations made in the Project Annual Report regarding the geological model as presently understood by the resident team.
- (3) To establish in the field the style of the mineral occurrences known and to attempt to locate further, in particular primary, occurrences.
- (4) To collect representative samples for laboratory investigation, assay and analysis in order to assist more detailed understanding of the style and mode of occurrence of the potential economic mineralisation.
- (5) To share the findings of the visit with relevant Ecuadorian personnel.
- (6) To assess the need for any future specialised input regarding the increased understanding of the mineral potential of the area.

July 27 Prepare and deliver an informal lecture on Volcanic Hazards and their Mitigation in Indonesia. Attend Project dinner, hosted by Ing. G Bixby, Gerente General, INEMIN.

July 29 Departure Quito for Miami.

3. WORK COMPLETED

- (1) During the visit 49 days were worked in the field and 18 in Quito (Total 67-thus completing the ODA requirement for three months work in terms of working days).
- (2) With the help of INEMIN staff a number of references and compilations of previous information were located and relevant material extracted. A number of mining and exploration companies also contributed data.
- (3) The field work commenced with a 4-day introductory visit led by Dr. J. Aspden and Ing. F. Viteri of the resident team. The remaining field work was carried out in company with Ing. Viteri and Sr. M. Céleri and involved travel by Landrover, mule and foot sometimes from tents or mining camps. 17 days were spent in the Sub-Andean Belt, 15 in the Tres Lagunas Granite Zone, 8 in the Shincata Collay Belt and the remainder in regional appreciation (mostly while travelling).
- (4) Over 200 samples of rock from 90 locations were collected for reference and future study and 45 composite pan samples were collected, mainly in an attempt to assess whether tin and tungsten mineralization is associated with the Tres Lagunas Granite Zone. These rock and heavy mineral samples are being shipped to the BGS laboratories in UK for further study (rock and pan sample lists are appended to this report).
- (5) Cooperation both in the office and field with the accompanying INEMIN geologist Ing. Viteri was both productive and a pleasure. Ing. Viteri kept invaluable notes and his efforts resulted in the traverse/sample location maps which are being prepared. Sr. Céleri acted as driver and as an invaluable field assistant. The efforts of these two men to make the visit a success cannot be overpraised.

4. SOME (BROAD) PRELIMINARY CONCLUSIONS

The following section is written 4 days after returning from the second of 2 extensive field sessions (commissions) and is in no way intended to be complete. However, some generalisations can be made at this point based on field observations only. (The analytical work planned is of course crucial before fully documented interpretation can be made).

- (1) The broad geological model, involving very large-scale tectonic events, would benefit from more detailed structural studies. E.g. two major events of contrasting styles are clearly visible over much of the semi-pelite unit both east of Cuenca and S of Loja. Both of these events are cut by the two mica 'S-type' granite at Loma del Inca which is itself undeformed.
- (2) **The Sub-Andean gold belt** includes at least four primary deposits of gold which are clearly associated with subvolcanic to volcanic intrusions younger than the regional Batholith. In one case, Piuntza, both intrusive and extrusive volcanic breccias and tuffs were observed, the presence of accretionary lapilli proving the latter. In two cases the intrusives were proved to be of highly evolved silicic composition and are probably vertically zoned from high level Au/Qz stockworks to Au/base metal veins and breccias at depth. In addition, three days were spent at Nambija during which 6 of the underground mining operations were visited. The primary deposits at Nambija (and presumably the nearby Campana, Campanilla and Guaysimi deposits) are atypical in that both major linear structures and the presence of extensive calc-silicate rocks (skarns) are major controls. However, much of the visible gold at Nambija is clearly the result of an event younger than the skarn as it occurs in quartz veinlets disrupting the calc-silicate host. A younger intrusive event is suspected here also.

The prospects of finding more primary base metal-gold deposits in the Sub-Andean belt are considered very likely.

- (3) **The Shincata-Collay belt** has long been the focus of alluvial Au workings but no primary occurrences are recorded. During this survey an old adit was re-discovered in the Río Ayllón which worked quartz veins cutting semi-pelites carrying Cu, Pb and Zn sulphides. Future assay of samples of this veinstone will show if gold is also present. Possibly the most important find in this belt was a float block composed of a quartz/arsenopyrite vein within which are visible gold grains. The margin of the vein is an altered volcanic of intermediate composition. A third indication is the presence of frequent river boulders of quartz/pyrite/sericite rock (clearly derived from a volcanic neck not visited to the SE of the Río Burro Playa) in an area of alluvial workings. In this belt also, therefore, there are indications that gold (and base metals) may be associated with younger (even Tertiary) subvolcanic intrusions.
- (4) **The Tres Lagunas Granite zone** delineated as a result of the project work is clearly of 'S-type' affinity and often is strongly deformed, even mylonitised, by a regional structural event. Tourmaline and muscovite are frequent and greisenisation sometimes occurs. In most cases, however, the strong post intrusion deformation obscures original contacts where mineralization might be most likely to occur. For this reason, heavy mineral sampling was often undertaken in streams draining the contacts. No Sn or W minerals were recognised in the rocks or pan, but any conclusions must wait for the analytical results.

Two small high-level intrusions of biotite/muscovite granite, at Loma del Inca and on the new road between Loja and Saraguro, have quartz/muscovite/tourmaline dykes and pegmatites, cutting greisenised semi-pelites. These occurrences are clearly post tectonic and, even though are of 'S-type' affinity, are almost certainly younger than the largely syn- or pre-tectonic Tres Lagunas Granite proper. Once again, no Sn or W (or base metal) was observed in likely rocks, but subsequent assay and analysis will throw more light on the economic possibilities of this (composite) suite of rocks. (When considering the two ages apparently demonstrated it is of interest that 'S-type', highly economic, granites of both Mesozoic and Miocene age occur in the Cordillera Real of Bolivia).

A further area of undeformed 'S-type' granite occurs in the Espiritu Playa area East of Gima; however, this can be shown to be increasingly tectonised as the (approx. 10 km wide) outcrop is traced westwards towards the Baños front. Of possible economic interest here are extensive areas of altered and sulphide impregnated granite associated with a younger granodioritic intrusion. In the western, more tectonised part of this granite are zones of metasediments at the contacts of which greisens are visible.

ACKNOWLEDGEMENTS

This visit was funded on the UK side by the Overseas Development Administration in terms of its bilateral technical cooperation agreement with Ecuador. The counterpart institution, INEMIN, under the direction of Ing. Guillermo Bixby, General Manager, provided general assistance, hospitality and local costs for the fieldwork. The staff of INEMIN attached to the Project, Ing. F. Viteri, Ing. M. Pozo, and Sr. M. Céleri, provided expert and personal support at all times. The project office is under the calm efficient control of Sra. Veronica Endara and she is particularly thanked for the preparation of this report and sample lists, at very short notice.

Dr. and Mrs. Aspden provided welcome hospitality and the British Embassy, in particular Mrs. F. Gristock and Mr. D. Brigenshaw, the requisite backup.

Numerous other people and organisations provided assistance including Ing. E. Salazar (BP Minerals), Bill Mathais (Cyprus Minerals), Chester Sellers (Sachacuri Mines), Tori Birkeland, Frank Van Thournout (Belgium Mission at INEMIN), Ing. Orbea and Ing. Bonifaz of the INEMIN regional office at Zamora, and Sr. Toledo (Piuntza concession area). At Nambija, members of the following sociedades allowed access to their workings and plant: Velazquez, Benitos, Playón, Reina del Cisne, Golden West, Castillo and Tocayos. At Chinapintza Soc. Cariamanga and Sr. Vincent Torres were most helpful.

The people of the field areas, in particular the locally engaged assistants and *muleteros* provided essential and friendly assistance.

Sr. Ing. Guillermo Bixby and his wife are particularly thanked for their hosting of a project dinner at the end of the visit.

LISTING OF ROCK AND PAN SAMPLES
Table 1. Rock samples collected during the first commission

SAMPLE No.	LOCATION	DESCRIPTION	ACTION NEEDED
CR-MC-1	West approaches to Sigsig. Prospect approx. 200m W of ADIT No. 1	Qtz-pyrite veining in schists # minor 2° Malachite + azurite stains	Assay vein + schist for Cu, Pb, Zn, Au, Ag.
CR-MC-2	Sigsig prospect immediately W of Portal ADIT No.2	5-6cm vein of 80% dark brown sphalerite replacing schistosity	Assay for Cu, Pb, Zn, Cd, Au, Ag.
CR-MC-3	Back Wall of ADIT No. 2	Chlorite - sericite schist or mylonite.	Prepare thin section; assay for Au.
CR-MC-4	as above	as above	as above
CR-MC-5	Contact zone of porphyry dyke 500m W of Peggy Main Mine	Cream young volcanic porphyry net veined by epidote	Assay for Au
CR-MC-6A	100m E of MC 5	Young volcanic-leucocratic porphyry dyke cut by chlorite-epidote veining	Prepare thin section. Assay for Au
CR-MC-6B	Contact with porphyry dyke above	Quartz sericite semi-schist or mylonitized granite	Prepare thin section. Assay for Au
CR-MC-7A	Peggy Mine - blocks from bridge - are assumed to represent main ore body	10% Chalcopyrite in grey quartz-chlorite matrix also pyrite, pyrrhotite + other sul.	Polish section Assay for Cu, Pb, Zn, Au, Ag, Sn.
CR-MC-7B	Peggy Mine dump, possibly from ADIT No. 2	Galena + sphalerite + minor other sulphides Brecciating cream volcanic host + breccia	Assay for Cu, Pb, Zn, Cd, Au, Ag
CR-MC-7C	as above	Pb, Zn + Fe sulphides cross cutting foliated granite	as above
CR-MC-7D	Peggy Mine dump - probably main ore body.	Complex range of sulphides + chlorite + tourmaline + SiO ₂ as alteration of fol. granite	Polish section Assay for Cu, Pb, Zn, Ni, Bi, Au, Ag, Sn, W
CR-MC-7E	Peggy Mine, between ADIT Nos. 2 and 3	Quartz + vuggy pyrite veinstone	Assay for Au + Ag
CR-MC-8	River boulders just below Peggy Mines	Relatively undeformed Tres Lagunas Granite mega feldspar + much biotite	Full major + minor element analysis
CR-MC-9	Loose landslide boulder from footpath E of Peggy Mine main ADIT	Schorl (tourmaline) - quartz rock - as replacement of foliated granite	Assay for Au, Ag, Sn + W
CR-MC-10A	Float from junction of Río Burro Playa + Río Tres Lagunas	Quartz - sericite - chlorite semi-schist	Assay for Au
CR-MC-10B	As above	Young volcanic host with sericite-chlorite in vuggy areas	Assay for Au
CR-MC-10C	As above	Young highly pyritic acid volcanic	Assay for Au
CR-MC-11	400m W of Tres Lagunas camp site	Tres Lagunas Granite with unusually high proportion muscovite approx < 4mm	Thin section analysis
CR-MC-12	N side of ridge between R Tres Lagunas and R. Huigra	Quartz-sericite schist of semi-pelite unit cut by 3mm quartz - pyrite veinlets	Assay for Au
CR-MC-13	Landslide debris 300m N of MC 12	Fold style (F2) in more quartzitic bands of semi-pelite unit	Describe and figure as structural example
CR-MC-14	100m upstream in Río Minas from junction with R Burro Playa	Stretched Tres Lagunas blue quartz granite with rodde quartz to L2	Thin section. Fig. as structural example
CR-MC-15A	50m upstream in Río Tres Lagunas from junction with R Huigra	Felsite (young acid volcanic) (forms cascade)	Assay for Au
CR-MC-15B	Float below above location	Relatively low tectonised Tres Lagunas Granite	Thin section analysis
CR-MC-15C	As above	Brecciated-flow banded leucocratic aphyric young volcanic	Assay for Au
CR-MC-15D	At above junction	Very finely foliated mylonitic quartz-sericite schist	Assay for Au
CR-MC-16	Río Burro Playa 200m downstream from junction with Río Minas	3cm zone of silicification with minor pyrite, cutting, sheared Tres Lagunas Granite	Assay for Cu, Pb, Zn, Au, Ag
CR-MC-17	As above	Crushed blue quartz Tres Lagunas Granite with minor sulphide	As above

Table 1. Rock samples collected during the first commission (Continuation)

SAMPLE No.	LOCATION	DESCRIPTION	ACTION NEEDED
CR-MC-18	As MC 10	Float of epidote - quartz rock	Assay for Au, Ag
CR-MC-19A	Río Burro Playa	Megacrystic Tres Lagunas Granite	Thin section
CR-MC-19B	As above	Float melanocratic young volcanic rock (MAG SUS 10.0)	Thin section Assay for Au
CR-MC-19C	As above	Float - highly sulphidic (pyrite) young leuco-volcanic with approx. 10mm quartz-xenoliths	Assay for Au, Ag
CR-MC-20	Río Minas as MC 14	Tectonised Tres Lagunas Granite with partially cataclased feldspar mega-cryst	Fig. as structural example
CR-MC-21	Near Río Camp site	Compact metaquartzite typical of semi-pelite unit in this area	Assay for Au
CR-MC-22A	E of Quebrada Reote, Peggy Mine area at porphyry dike	Brecciated young volcanic with silica + some sulphide	Assay for Au, Ag
CR-MC-22B	As above	Similar to above, mainly sulphidic silica	As above
CR-MC-22C	As above	Cream quartz porphyry dyke	As above
CR-MC-23	Float on path approx. 1km SSE Peggy Mine	Oxidized quartz-chlorite epidote rock	As above
CR-MC-24	Float in Río	Fresh melanocratic metavolcanic with minor sulphide	Thin section Assay for Au
CR-MC-25A	Ore piled at entrance of blocked ADIT in E bank R Ayllón	Quartz veinstone with br'td semi-pelite inclusions. Considerable pyrite, minor galena + sphalerite and traces of bornite. Two generations of quartz the latter being drusy	Assay for Cu, Pb, Zn, Bi, Au, Ag
CR-MC-25B	As above	Similar to above	As above
CR-MC-25C	As above	Similar to above	As above
CR-MC-25D	As above	Another sample of stacked ore	As above + polish section
CR-MC-26A	Float 30m upstream from MC 25	Quartz brecciated with quartz-pyrite infill	Assay for Au, Ag
CR-MC-26B	Float 30m downstream from MC 25	Silicified semi-pelite with approx. 2% chalc-pyrite	Assay for Cu, Pb, Zn, Au, Ag
CR-MC-26C	As above	As above	(Blank)
CR-MC-27A	Float in Río Ayllón 400m above campsite	Quartz veinstone with arsenopyrite and ?gold in contact with volcanics	Polish sections, careful cutting, probe-work. Assay for Au, Ag
CR-MC-27B	As above	Folded semi-pelite with So, S1 + S2	Fig. as structural example
CR-MC-27C	100m below above (float)	Younger volcanic similar to that as selvages in 27A	Thin section
CR-MC-28	Float Río Santa Barbara	Silicified semi-pelite with chalcopyrite. Similar to 26B	Assay for Cu, Pb, Zn, Au + Ag
CR-MC-29A	Float blocks from alluvial workings in Río San Francisco near Gualaceo - Limon road	Epidote-quartz-chlorite rocks in general, some with pyrite	Assay representative portions for Au, Ag
CR-MC-29B	Float blocks from alluvial workings in Río San Francisco near Gualaceo - Limon road	Epidote-quartz-chlorite rocks in general, some with pyrite	Assay representative portions for Au, Ag
CR-MC-29C	Float blocks from alluvial workings in Río San Francisco near Gualaceo - Limon road	Epidote-quartz-chlorite rocks in general, some with pyrite	Assay representative portions for Au, Ag
CR-MC-29D	Float blocks from alluvial workings in Río San Francisco near Gualaceo - Limon road	Epidote-quartz-chlorite rocks in general, some with pyrite	Assay representative portions for Au, Ag
CR-MC-29E	Float blocks from alluvial workings in Río San Francisco near Gualaceo - Limon road	Epidote-quartz-chlorite rocks in general, some with pyrite	Assay representative portions for Au, Ag
CR-MC-30	As above	Spongy pyritic mass but has Mag. sus. of + 50. Probably included pyrrhotite	Polish section. Assay for Au, Ag, Ni
CR-MC-31	Road crossing Tampanchi ultrabasic body	Medium grained biotite (+ muscovite) dyke, cutting ultra - basic (Mag. sus. = 0.25)	Analysis

Table 2. Rock samples collected during the second commission

SAMPLE No.	LOCATION	DESCRIPTION	ACTION NEEDED
CR-MC-32	Palanda-Zumba road	Young volcanic with epidote veins chlorite, sulphide	Assay for Au
CR-MC-33A	S bank Río Mayo	Fresh e.g. Río Mayo granodiorite	Analyses
CR-MC-33B	S bank Río Mayo	Río Mayo granodiorite with 1mm Cu vein	Assay for Au
CR-MC-34	S Bank Río Mayo	Float metavolcanic with disseminated pyrrhotite	Assay for Au
CR-MC-35A, B, C; 36 a 42	Las Planas (Sachacuri) prospect (13 samples)	Quartz veins, minor stockworks, some with pyrite	Assay for Au select for fluid
CR-MC-43A	R San Francisco at Sachacuri	Quartz vein with sulphides	Assay for Au
CR-MC-43B	Río San Francisco at Sachacuri	Sulphidic andesitic tuff	Assay for Au
CR-MC-44A	Río Afiladeras, N of Sachacuri	Lapilli tuffs with disseminated sulphides	Assay for Au
CR-MC-44B	Río Afiladeras N of Sachacuri	Silicified tuffs with disseminated sulphides	Assay for Au
CR-MC-45	Old road W of Río Mayo	Altered volcanic rock plus magnetite and epidote	Assay for Au plus thin section
CR-MC-46A, B, C	Main road S of Palanda	Silicified, chloritised, sheared Gd.	Assay for Au plus thin section
CR-MC-47 a 49	Loma del Inca (E of Quilanga)	Granites, quartz-tourmaline veins and greisens	Assay for Sn-W
CR-MC-50A, B, C; 51; 52A, B	North margin of Malacatos basin	Tourmaline bearing tectonised Tres Lagunas Granite	Select examples for Sn-W Assay and thin sections
CR-MC-54A, B, C, D	Piuntza prospect	Volcanic breccias, with sulphides	Select and assay for Au
CR-MC-55	Piuntza prospect	Quartz-feldspar porphyry with Au bearing sulphidic veinlets	Assay for Au
CR-MC-56A	Piuntza prospect (Circo area)	Quite fresh quartz-feldspar porphyry	Assay for Au analysis
CR-MC-56B	Piuntza prospect (Circo Area)	Mineralised meta-sediments clast in v. Br.	Assay for Au
CR-MC-56C	Piuntza prospect (Circo area)	Mineralised v. Br.	Thin section and analysis
CR-MC-57A	Piuntza prospect (Río Piuntza)	Mineralised v. Br.	Assay for Au
CR-MC-57B	Piuntza prospect (Río Piuntza)	Tuff with accretionary lapilli	Figure
CR-MC-58	Piuntza prospect (Río Piuntza)	Quartz vein with pyrite and anhydrite?	Examine and assay for Au
CR-MC-59	Piuntza prospect (Río Piuntza)	Silicified, altered fault rock	Examine and assay for Au
CR-MC-60	Quarries and dumps top of Mapasingue	Volcanic, open quartz veins, chalcopryrite	Identify and assay
CR-MC-61	Mapasingue Alto (Nambija)	Volcanic cut by chlorite/pyrite	Identify and assay
CR-MC-62	Mapasingue Alto (Nambija)	Fractured and mineralised volcanic	Identify and assay
CR-MC-62B	Mapasingue Alto (Nambija)	Epidote-quartz-calcite chalcopryrite	Examine and assay
CR-MC-63A, B, C	Mapasingue Alto (Nambija)	Volcaniclastic low grade ore	Examine and assay
CR-MC-63D, E	Playón Main Mine	Disseminated mineralisation	Examine and assay
CR-MC-64	Playón Main Mine	Various ore types	Examine and assay

Table 2. Rock samples collected during the second commission (*Continuation*)

SAMPLE No.	LOCATION	DESCRIPTION	ACTION NEEDED
CR-MC-65 (2 bags)	Arco (Nambija)	Various ore types	Examine and assay
CR-MC-66	Arco Golden West	Various ore types	Examine and assay
CR-MC-67	Mapasingue Castillo	Quartz sulphide ore	Examine and assay
CR-MC-68	Mapasingue Tocayos	Typical dump material	Examine and assay
CR-MC-69	Blocks in Río Campana	Campana breccia ore	Examine and assay
CR-MC-70	R. Chinapintza bridge	Altered and veined granodiorite	Examine and assay
CR-MC-71	Chinapintza approach road	Sheared and altered granodiorite	Examine and assay
CR-MC-72	Río Nambija	Fresh micro-granodiorite	Thin section and analysis
CR-MC-73	Chinapintza first shops	Oxidised vein cutting Gd	Assay
CR-MC-74	Mule track to Chinapintza	Pale-porphyry dyke	Thin section and assay
CR-MC-75	Mule track to Chinapintza	Similar with silicification	Assay
CR-MC-76	Mule track to Chinapintza	Similar with silicification	Assay
CR-MC-77	Chinapintza west sector	Heavily oxidised vein	Assay
CR-MC-78A-D	Chinapintza west sector	Fresh Cu, Pb, Zn, Ag sulphides in Br.	Polish section, assay figure
CR-MC-79A, B	Chinapintza SW sector	Oxidised veinstone	Assay
CR-MC-83A	Post tectonic granite N of Loja	2 Mica pegmatitic granite	Thin section - Analysis
CR-MC-83B	Mule track to Espiritu Playa	Quartz vein with tourmaline	Assay for Sn/W
CR-MC-84	Mule track to Espiritu Playa	Quartz vein with sulphide	Assay for Au
CR-MC-85A, B	Mule track to Espiritu Playa	Greisens	Thin section Assay for Sn/W
CR-MC-86	Río Chaufe (Espiritu Playa)	Float sulphidic quartz rock	Assay for Au
CR-MC-87A, B	Río Chaufe (Espiritu Playa)	Greisens and quartz contact rock	Assay for Au/Sn/W Thin section
CR-MC-88A	Rb trib. of Espiritu Playa	Altered and sulphidic granite	Assay for Cu/Pb/Zn/Au. Thin section
CR-MC-88B	Rb trib. of Espiritu Playa	Sulphidic rich shear zone in above	Assay for Cu/Pb/Zn/Au
CR-MC-89	Río Chaufe (Espiritu Playa)	As MC 88A	Assay for Cu/Pb/Zn/Au. Thin section
CR-MC-90	Río Cambana (N Nambija)	Dense banded pyrite/chlorite rock	Assay for Cu/Pb/Zn/Au
CR-MC-91	Río Jadan (E of Cuenca)	Fractured and sulphide rich chert	Assay for Cu/Pb/Zn/Au. Thin section
CR-MC-92	Unknown (Palanda area?)	Altered diorite and large pyrite/quartz	Assay for Au

Table 3. Listing of pan (heavy mineral) samples

CODE	LOCATION	COORDINATES	TOPOGRAPHIC /CENSUS SHEET, 1:50000
MC-P-01	Río San Francisco	5580-7140	Córdova (Census)
MC-P-02	Río Shío	Principal	Sigsig
MC-P-03	Río Chorro Blanco	Principal	Sigsig
MC-P-04	Tres Lagunas	Tres Lagunas	Sigsig
MC-P-05	Tres Lagunas	Tres Lagunas	Sigsig
MC-P-06	Quebrada Huigra	Loma Fasañán	Sigsig
MC-P-07	Unión (Huigra and Tres Lagunas)	Loma Fasañán	Sigsig
MC-P-08	Chorro Blanco	Loma Fasañán	Sigsig
MC-P-09	Río Minas	Loma Fasañán	Sigsig
MC-P-10AB	Río Burro Playa	Burro Playa	Sigsig
MC-P-11	Río Minas	Loma Chancay	Sigsig
MC-P-12AB	Río Alcalcay	Alcalcay	Sigsig
MC-P-13	Río Santa Bárbara	4762-5785	Sigsig
MC-P-14	Cueva de Gallos	4880-5482	Sigsig
MC-P-15	Río Santa Bárbara (MS)	4880-5482	Sigsig
MC-P-16AB	Río Ayllón	Huacospamba	Sigsig
MC-P-17	Quebrada Oscura	Loma Obscuridad	Sigsig
MC-P-18	Santa Bárbara	Loma La Esperanza	Sigsig
MC-P-19	Río Ayllón	Loma La Esperanza	Sigsig
MC-P-20	Río Culebrillas	4885-5390	Sigsig
MC-P-21	Río Quebrado	4758-5698	Sigsig
MC-P-22	Quebrada Reote	4736-5840	Sigsig
MC-P-23	Río Mayo	1414-5420	Zumba
MC-P-24	Río San Francisco	2462-5812	Zumba
MC-P-25	Río Afiladeras	2305-6385	Zumba
MC-P-26	Quebrada Bejucales	2054-6212	Zumba
MC-P-27	Quebrada Sinchama	2040-6130	Zumba
MC-P-28	Quebrada Filaderos	2008-6086	Zumba
MC-P-29	Quebrada Nauchi	1855-5966	Zumba
MC-P-30	Quebrada San Francisco	9416-3752	Gonzanamá
MC-P-31	Quebrada Jaramillo	9210-3880	Gonzanamá
MC-P-32	Quebrada Naranjo Dulce	9025-4015	Nambacola
MC-P-33	Río Nangora	9816-3805	Vilcabamba
MC-P-34	Área Tunantza	3380-4530	Zamora
MC-P-35	Río Piuntza	3371-4468	Zamora
MC-P-36AB	Pequeño afluente	9196-7236	La Toma
MC-P-37AB	Río Aguarmeda	0531-9728	Saraguro
MC-P-38	Río Aguarmeda	0577-9684	Saraguro
MC-P-39	Pequeño afluente	0602-9790	Saraguro
MC-P-40	Pichanal	0641-9844	Saraguro
MC-P-41	Quebrada	Pullca Urco	Sigsig
MC-P-42AB	Río Chauli	Espíritu Playa	Sigsig
MC-P-43	Quebrada	Espíritu Playa	Sigsig
MC-P-44	Quebrada Azul	Espíritu Playa	Sigsig
MC-P-45	Quebrada Pequeño	Espíritu Playa	Sigsig

APPENDIX 4

Draft Final Report

**Contribution to the understanding of the Mineral Potential of the
Southern Ecuadorian Andes**

by

M. C. G. Clarke, BSc., PhD, MIMM

BGS

Report No. WC/89/ /R

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NB. REF. 1 and 2 (which comprise some of the results of this work) are submitted separately

REF 1 = Appendix 6 in this Annual Report

REF 2 = Appendix 5 in this Annual Report

Contribution to the understanding of the mineral potential of the Southern Ecuadorian Andes

DRAFT FINAL REPORT

1. INTRODUCTION

This work represents a specialised input into the ongoing bilateral Cordillera Real Project, which commenced in 1986 and is due for completion in 1990. The project has made considerable progress in understanding the regional geological framework and it was considered that the various mineral occurrences encountered in the Project area required a more detailed study.

The UK Project Manager, Dr Litherland, requested that this study concentrate on the southern part of the Project Area and on the mode of occurrence and genesis of primary mineralisation particularly in the following 3 mineral “belts” (as defined in the Annual Report of the Project for 1987-1988):

(a) Sub-Andean Gold Belt

This is geographically associated with a volcano-plutonic complex in the SE part of the Project area and was known to include the important skarn related Nambija type primary deposits.

(b) Collay-Shincata Gold Belt

The zone is geographically confined to the western part of the Cordillera Real, essentially between the main Andean watershed and the ‘Baños front’. Within this area are some of the famous ancient alluvial mining areas. No primary sources known.

(c) Tres Lagunas ‘tin-tungsten’ belt

This belt is defined as the result of the recognition of a suite of ‘S-type’ granites associated with a zone of very strong deformation, the Baños front. Both the granites and the deformation are interpreted by the resident Project geologists as being the result of collision tectonics.

2. WORK CARRIED OUT

(a) In Ecuador

- (1) Assessment of the archived material available in Quito.
- (2) Visits to representative areas and mineral localities in the three belts, to establish in the field the style of the mineral occurrences known and to attempt to locate further, in particular primary, occurrences.
- (3) Collection of representative samples for laboratory investigation, assay and analysis in order to assist more detailed understanding of the style and mode of occurrence of mineralisations found.

An outline of the work carried out in Ecuador is given in the visit report BGS No: WC/88/29/R. (Clarke 1988) (Appendix 3 in this Annual report).

(b) In UK

The work carried out included the preparation and examination of 61 panned heavy mineral samples for the presence of gold, cassiterite and scheelite, gold and silver assay on 120 rock samples, analysis of 35 samples for a suite of base metals including tin and tungsten and full major and trace element analysis of 19 granites and related rocks. Additional mineralogical studies were carried out on 19 ore samples using reflected light and electron probe techniques, and 9 granites and 9 samples of altered rock for transmitted light petrography.

The pan sample and reflected light/probe work was carried out by Dr B. Beddoe-Stephens and his report is appended and referred to here is (Ref. 1: See Appendix 6 in this Annual Report). The petrographic (thin section) study was the work of Dr J. Dangerfield whose report, also appended, is referred to as (Ref. 2: See Appendix 5 in this Annual Report). Detailed examination of one sample of silver-based metal ore was carried out by Dr. N. J. Fortey (Ref. 3).

The precious, base metal and major and minor element rock analyses were carried out under contract by Messrs. Caleb Brett Ltd on samples selected by M.C.G.C.

The overall interpretation of the results and preparation of this report was carried out by M.C.G.C - consultation and comments are welcomed at this stage before the report is finalised.

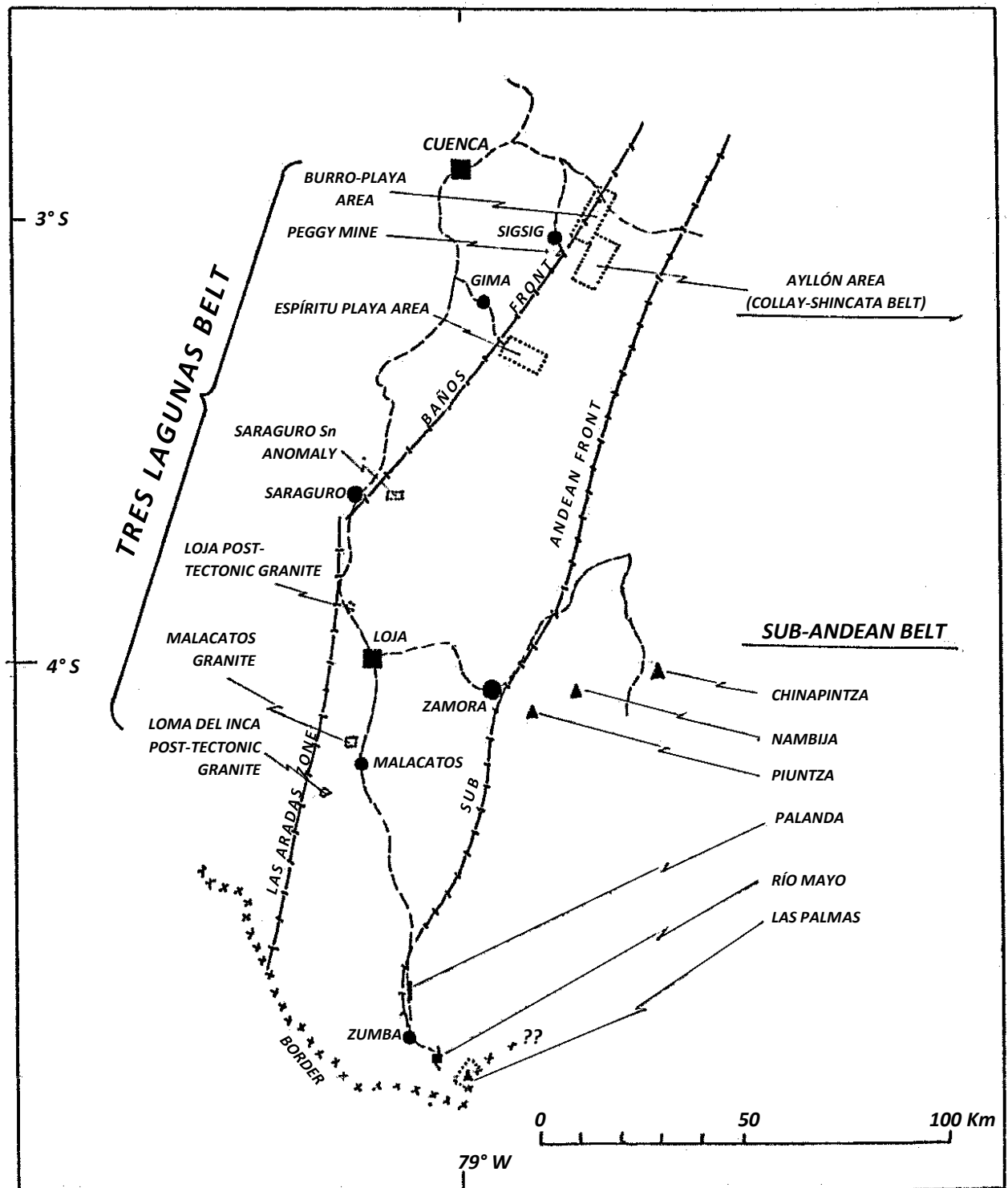


Figure 1. Location of areas investigated in relation to major tectonic features

3. SUMMARY OF IMPORTANT OBSERVATIONS AND CONCLUSIONS

3.1 Sub-Andean Gold Belt

- (a) In addition to the skarn-type style of rich gold deposit exemplified by Nambija a second group has been established, related to high level, highly evolved stocks of typically quartz and feldspar porphyries.
- (b) This style was recognised at Piuntza, associated with both intrusive and extrusive pyroclastics and at Chinapintza where the porphyry body and satellite dykes intrude and strongly alter the regional granodiorite. Neither case was previously documented.
- (c) Gold in the primary rock was found at both areas, more notably at Chinapintza, where it is accompanied by base-metals and silver.
- (d) The Los Planes prospect is also probably of related type and superficial differences between these three results from the different levels of exposure at each, being lowest, i.e. most dissected, at Chinapintza and highest at Los Planes.

It is concluded that the high level, geochemically evolved late-stage intrusions within the Sub-Andean Belt have a very high gold potential and that one of the first indications is the presence of dykes or stocks (in outcrop) or float equivalents, of quartz-feldspar porphyry - preferably showing argillic or other alteration.

Another indication is the presence of propylitized granodiorite, especially when this alteration borders minor sulphide mineralised fractures.

3.2 Collay-Shincata Gold Belt

- (a) Vein samples from a relocated abandoned adit in the Ayllón area carry extremely high contents of gold together with silver and base-metal sulphides including antimony.
- (b) Free gold was also observed in quartz vein float, associated with arsenopyrite and cutting a dioritic rock.
- (c) The drainages in the Ayllón area frequently carry gold and scheelite grains but no cassiterite.
- (d) Very extensive alluvial mining operations were carried out formerly, judging by the stacked waste.

It is concluded that the Ayllón area has a very high hard rock gold potential which could, initially, be substantiated by detailed outcrop and drainage (float) mapping. Stream sediment geochemistry utilising, inter alia, antimony as a pathfinder should also be considered.

The presence of sulphides of copper, lead, zinc and antimony indicates that the area may additionally have polymetallic mineral potential.

3.3 Tres Lagunas Granite suite

- (a) The suite has both syntectonic and post tectonic examples.
- (b) The mineralogy is that of 'S' type granites (s.l.).
- (c) The geochemistry shows the suite to be somewhat intermediate between 'S' and 'T' types.
- (d) The generally low tin and tungsten content and lack of cassiterite in pan samples from drainages crossing the outcrops indicates that the suite has a low economic potential.
- (e) The geochemistry shows the examples analysed to be extremely unspecialised, or poorly enriched in incompatible trace elements, e.g. Rb, Y, compared with tin granites generally.

It is concluded that the T.L.G. is not a normal cordilleran 'T' type but neither is there evidence that it has much, if any, regional potential as a locus of a tin province. It is considered likely that it has a greater than normal crustal component compared with other cordilleran granites. This equates well with the possibility that the suite is collision related.

3.4 Peggy Mine area

This abandoned mine is listed as an example of a deposit from the 'Polymetallic Belt' and was not originally one of the target areas for the investigation described here. It was, however, examined for comparative purposes and some significant features observed:

- (a) Base metals, particularly copper, lead and zinc, sulphides were the main target of the previous mine, occurring as veins, stockworks and breccias hosted by typically strongly deformed Tres Lagunas Granite.
- (b) Wolframite and Stannite have been identified during this study, but together with the sulphides and the frequent tourmaline, post-date the deformed granite.
- (c) Silver, tin and tungsten values are high in some samples.
- (d) A number of quartz-feldspar porphyry dykes and stocks also post-date the T.L.G. and Baños Front deformation and carry tourmaline in late veinlets and pyrite plus (in one sample) gold, as late-stage phenomena.

It is concluded that the polymetallic mineralisation (including Sn and W) is most probably related to the intrusion of the high-level, post tectonic, quartz porphyry intrusions and not to the intrusion or deformation of the Tres Lagunas Granite.

There is a possibility that economic silver-tin-tungsten mineralisation exists, perhaps of Bolivian type. Detailed examination of the area, particularly of the most evolved post tectonic intrusives is recommended in order to check out that possibility further.

4. LISTING OF PAN SAMPLE RESULTS**Table 1.** Pan concentrate data

Area	Sample #	Mass (grams)	%Mag (1)	%Heavies (2)	Cassiterite (3)	Scheelite (4)	Gold (5)
Burro Playa, etc. area	1	58.1	1.4	84.2			Few large grains
	2	56.3	62.4	33.9		3	
	3A	20.7	42.2	47.5		1	
	3B	23.7	28.0	43.1		?1	
	4	6.1		19.3			
	5A	40.6	<0.2	23.4			
	5B	4.3		20.9		1	
	5C	32.8	<0.2	33.2			
	5D	62.5		21.2			
	6A	22.4	26.6	45.0		1	
	6B	43.0	22.8	41.9			
	7	35.5	<0.3	15.5			Several grains
	8	23.9	21.8	52.1		2	1 grain
	9A	18.4	10.6	51.8			Few grains
	9B	50.5	0.4	51.8			
	10A	18.6	<0.5	45.6			
	10B	33.2	0.3	35.9			
Peggy	11	56.4	0.4	30.7			
	12A	77.0	1.7	37.2		?1	
Peggy	12B	21.1	<0.5	13.9			
	13	69.7	46.2	46.1	Few grains	30	Several grains
Ayllón area	22	37.5	1.6	48.8	Common		
	14	19.8	13.7	41.1		40	Many tiny grains
	15	34.3	0.9	30.9		10	Many grains
	16A	33.6	4.0	36.4		30	Several tiny grains
	16B	10.3	<1.0	7.0			
	17	26.4	<0.5	20.5		30	3 small grains
	18	43.1	<0.2	42.3		>100	1 small grain
	19	37.8	10.4	46.4		20	1 small grain
	20	10.7	30.5	30.5		6	
	21	7.7		33.3		5	
Los Planes	23	136.5	59.8	34.0		15	1 small grain
	24	261.8	69.5	29.7			4 small grains
	25	156.3	78.0	20.1			1 small grain
	26	42.4	67.3	30.3			
	27	130.2	80.4	14.0			
	28	238.6	68.5	29.4			3 small grains
	29	55.6	86.6	10.8			
Malacatos	30	39.4	0.8	35.2		5	
	31	31.1	<0.3	21.3		?1	
	32	43.3	1.0	10.2		?1	
	33	37.6		26.0			
Piuntza	34	33.2	12.3	11.7			Several small grains
	35	35.9	18.2	43.3			4 small grains
Loja	36A	9.4	19.6	47.8			
	36B	45.9		7.3			
Saraguro	37A	36.4	32.4	52.3			
	37B	114.7	39.2	54.9			
	38	193.6	36.8	49.6			
	39	133.2	24.0	18.3			
	40	118.8	24.8	22.6	Common	50	
Espíritu Playa	41	40.1	6.9	12.9			
	42A	26.1	35.3	18.2			
	42B	189.2	64.8	15.2			
	43	131.6	37.7	19.3			
	44	159.4	61.9	6.5			
	45	73.3	62.3	5.6			
	46	109.1	14.1	17.1			
Los Planes	47	2.5					Many tiny grains
Pilares (Río Collay)	48	1.1					Several small grains
Río Collay (Cabeceras)	49	9.5				2	2 grains

(1) Percentage Magnetite; (2) Percentage concentrate >2.9 density; (3) Results of 'tinning' on non-magnetic fraction;
 (4) Approx. number of grains seen in short wave UV light; (5) Qualitative assessment of no. of gold grains.

5. DETAILS OF THE FIELD AND LABORATORIES WORK BY AREAS

The areas investigated are indexed on Fig. 1 and listed here:

- 5.1 Peggy Mine
- 5.2 Burro Playa, Principal and Río San Francisco areas
- 5.3 Ayllón area
- 5.4 Nambija area
- 5.5 Piuntza and Chinapintza primary gold prospects
- 5.6 Palanda and Río Mayo areas
- 5.7 Los Planes prospect (Sachacuri) and adjacent traverse
- 5.8 Loma del Inca, Loja and Malacatos granites
- 5.9 Espíritu Playa and Saraguro areas

There follows data for individual areas under the headings:

Outline geology

Base and precious metal analytical data

Pan sample data

Mineralogical investigations

General conclusions

Tables of assay data and listings of sample type and location follow the notes on each area.

5.1 Peggy Mine

5.1.1 Outline geology

Base metal sulphide veins and stockworks have been mined previously on both sides of the river in this area. They are located within a zone of strongly deformed gneissic megacrystic biotite granite, quartz sericite schist and mylonite which are expressions of the proposed Baños Front collision zone of Litherland & Aspden.

The mineralised structures cross cut or replace the Baños Front fabrics as do a group of Quartz-feldspar porphyry dykes and stocks which are best exposed in the vicinity of a small east bank tributary - Quebrada Reote.

5.1.2 Base and Precious metal analytical data (Table 2a, b)

Values of base metals reflect the sulphides observed with Zinc being most prominent. Up to 222 g/t (7 oz) silver was recorded as is significant tin (up to 0.75% in MC-2) and tungsten (up to 0.6% in MC-7A & B). In only one sample was more than 1 ppm gold recorded and this is a marginal zone of one of the porphyry intrusions.

The silver to gold ratio is over 100:1.

5.1.3 Pan Sample Data (Table 1)

Only two samples relate to this area, P22 from Quebrada Reote, carries 'common' cassiterite, the other, P13, from the main stream, carries a few grains. Samples from further upstream do not carry visible cassiterite. The sample P13 carries gold and an artisanal gold washing operation is present nearby; scheelite also occurs. Both gold and scheelite are common in the upper reaches of this drainage in the Ayllón area (see section 3).

5.1.4 Mineralogical Investigation (see Appendix 6 in this Annual Report)

Two samples of ore, believed to originate from the main mine (MC-7A & D) confirmed the presence of a wide suite of base metal phases including wolframite. Tourmaline and quartz are the main gangue minerals and late-stage carbonate occurs. Sulphides include arsenopyrite, chalcopyrite, pyrite-marcasite, pyrrhotite and late bismuthinite. The wolframite predates the sulphides but tourmaline may be later than both.

Sample MC-9 is similarly tourmaline rich but carries no sulphides. MC-7a, from Adit No 2, comprises much sulphide, mainly galena, sphalerite and pyrite-marcasite intergrowths. Stannite ($\text{Cu}_2\text{FeSnS}_4$) was observed in this sample, but MC-22a from the Reote porphyry carries fine tourmaline in the quartz-sericite matrix and in thin late quartz veinlets. Tourmaline was also identified in a thin section of the Reote porphyry (MC-6a) (see Appendix 5 in this Annual Report).

5.1.5 General conclusions

The rich sulphide ore of the main mine, the veins and stockworks of Adit No. 2 and the porphyry intrusions all post-date the strongly deformed granite and semi-schists (mylonites) of the area. Tourmaline is very common, even post-dating the porphyry and together with the tin and tungsten and sulphide deposition is believed to represent an event younger than either the emplacement or deformation of the granites. The poly-metallic mineralisation episode is probably associated with intrusion of the porphyry bodies, i.e. it is considered unlikely that the tin and tungsten mineralisation is an earlier separate event associated with the granite. The locally high tin, tungsten and silver values (MC-2) are reminiscent of the similar ore element suite and sub-volcanic association elsewhere in the Andean Cordillera, e.g. Antamina in Peru, and, more especially, in the Cordillera of Bolivia.

Table 2a. Peggy Mine samples

Sample	Au (g/t)	Ag (g/t)	Cu%	Pb%	Zn%	Cd%	Sb%	Bi%	As (ppm)	W (ppm)	Sn (ppm)
MC-1	0	0	0.03	0	0.01	0	0	0			
MC-2	0.19	222	0.7	0.21	31.1	0.265	0	0	52	36	7684
MC-3	0	2									
MC-4	0	0									
MC-5	0	2									
MC-6A	0	1									
MC-6B	0	2									
MC-7A	0.66	119	6.38	0.03	0.18	0.001	0.02	0.58	57129	5846	606
MC-7B	0.3	182	0.52	0.47	29.7	0.186	0.02	0.01	57495	5979	580
MC-7C	0.1	79	0.03	1.06	1.54	0.008	0	0	574	32	236
MC-7D	0.09	9	0.4	0.01	0.07	0	0	0.02	30271	447	216
MC-7E											
MC-9	0.03	4								30	446
MC-22A	0.02	2									
MC-22B	2	31									
MC-22C	0	4									
MC-23	0	0									
MC-24	0.02	0									

Table 2b. Peggy Mine samples

MC-1	200m north of most northerly adit (adit no. 1). Quartz-pyrite veinlets cutting schist. Minor malachite staining.
MC-2	North side of portal to adit No. 2. 5-6 cm vein of dark brown sphalerite which appears to have cross cut and replaced the schistosity of the host rocks.
MC-3	Back wall of adit No. 2. Chlorite-sericitic schist or mylonite.
MC-4	Same location. Similar sample.
MC-5	500 m north of Peggy Mine, contact zone of young quartz-feldspar porphyry cutting schists. Porphyry sample net veined with epidote.
MC-6A	100 m south of MC 5. Similar sample.
MC-6B	Same location. Schist or mylonite at contact with porphyry.
MC-7A	Blocks from old bridge supports at mine. Chalcopryite, galena, pyrite, etc - probably typical ore from main mine.
MC-7B	Dump material, probably from adit no. 2. Galena and sphalerite and other minor sulphides.
MC-7C	Same location. Pb, Zn, etc sulphides in veinlets cutting foliated granite.
MC-7D	Peggy Mine Dump. Complex assemblage of sulphides and tourmaline as alteration of foliated granite.
MC-7E	North of mine. Float of quartz-pyrite rock.
MC-9	100 m SE of Main Dumps. Float from landslide of black radiating quartz-tourmaline rock replacing foliated T.L. Granite.
MC-22A	Immediately south of Quebrada Reote. Brecciated quartz-feldspar porphyry with silicified and sulphidic areas.
MC-22B	Same location. Similar sample.
MC-22C	Same location. Less altered porphyry dyke.
MC-23	Path 0.75 km southeast of Peggy Mine. Oxidized quartz-chlorite-epidote rock.
MC-24	

5.2 Burro Playa, Principal and Río San Francisco areas

5.2.1 Geology outline

This area straddles the north-north-west strike extension of the Baños Front as exposed at Peggy Mine, and includes some streams to the east, which drain the western flank of the Cordillera Real. The rocks here are mainly a semi-pelitic unit with two deformations, the second of which produces a prominent subhorizontal lineation with an Andean trend. This refolds tightly to isoclinally folded sediments of continental slope origin. Younger intrusions and volcanic necks are also present. Very little mineralisation was observed with the exception of gold bearing alluvials revealed by artisanal gold mining.

5.2.2 Base and Precious metal analytical data (Table 3a, b)

In general, all values obtained are very low reflecting the lack of mineralisation observed. Of seventeen samples assayed for gold and silver, only MC-30 gave a value higher than trace - this is a float of massive pyrite from an alluvial concentration in the Río San Francisco. The tin and tungsten values obtained can be considered to be within background and together with the lack of cassiterite reported in the pan samples indicate that the granites of the 'Baños Front' have little tin potential on the available data.

5.2.3 Pan sample data (Table 1)

No cassiterite was reported from any of the twenty samples collected. Gold was recorded in four samples, all of which are from areas known to the artisanal alluvial miners. Occasional isolated grains of scheelite were recorded but far less than in the adjacent Ayllón area.

5.2.4 Mineralogical investigations

The lack of observed mineralisation resulted in no samples being submitted for polished section investigation. Three samples were submitted for petrographic determination of the alteration minerals present. They are all of volcanic origin – MC-18 now altered to epidote and quartz, MC-19B to chlorite and carbonate and 19C is reported to include gypsum, pyrite, hematite and chalcedonic silica indicating modification, by fumarolic activity, of a pyroclastic, possibly of dacitic origin (see Appendix 5 of this Annual Report).

5.2.5 General conclusions

Little evidence of mineralisation was found. The granites do not appear to be tin and tungsten prospective and no indications of economic sulphides were seen. Gold occurs in the alluvial deposit of the drainages, together with numerous float blocks of altered young volcanics. One large volcanic neck was seen to lie east of the Río Burro Playa and could repay detailed examination and sampling, with gold/silver as the target.

Table 3a. Burro Playa, Principal and Río San Francisco areas

Sample	Au (g/t)	Ag (g/t)	Cu%	Pb%	Zn%	Cd%	Sb%	Bi%	As (ppm)	W (ppm)	Sn (ppm)
MC-10A											
MC-10B	0	0									
MC-10C	0.04	0									
MC-11	(Full analysis)									2	9
MC-12	0	0									
MC-13	(Structural sample)									0	8
MC-14	(Full analysis)										
MC-15A	0	0									
MC-15B	(Full analysis)									0	6
MC-15C	0	0									
MC-15D	0.01	0									
MC-16	0	0	0	0.01	0.02	0	0	0	103	14	15
MC-17	0	0	0	0	0	0	0	0	78	10	9
MC-18	0	0									
MC-19A	(Structural sample)										
MC-19B	0.01	0									
MC-19C	0	0	0.01	0	0	0	0	0	53	6	16
MC-20	(Structural sample)										
MC-21	0.01	0									
MC-29A	0	0									
MC-29B	0	0									
MC-29C	0	0									
MC-29D	0	0									
MC-30	1.01	2	0.11	0.01	0	0	0	0	25	10	4

Table 3b. Burro Playa, Principal and Río San Francisco areas

Burro Playa area	
MC-10A	Junction of Ríos Burro Playa and Chorro-Blanco. Float of quartz-sericite-chlorite semi-schist.
MC-10B	Same location. Volcanic hosting sericite-chlorite in vugs.
MC-10C	Same location. Highly pyritic acid volcanic.
MC-11	Ridge between Ríos Huigra and Tres Lagunas. Muscovite rich Tres Lagunas granite.
MC-12	2 km to northeast. Quartz-sericite schist cut by 3 mm quartz - pyrite veins.
MC-13	300 m north of MC-12. F2 folds in semi-pelite unit.
MC-14	100 m upstream in Río Minas from junction with Río Burro Playa. Blue quartz bearing rodded Tres Lagunas Granite.
MC-15A	50 m upstream in Río Tres Lagunas from junction with Río Chorro Blanco. Untectonised acid volcanic or dykerock.
MC-15B	Float at same location. Tres Lagunas Granite relatively fresh and untectonised.
MC-15C	Same location. Flow banded, aphyric volcanic rock.
MC-15D	At junction. Finely foliated mylonitic quartz-sericite schist.
MC-16	In Río Burro Playa 200 m below junction with Río Minas. 3 cm silicified zone with minor pyrite, cutting T.L. granite.
MC-17	Same locality. Crushed T.L. granite with minor pyrite.
MC-18	Locality as MC-10. Float of epidote-quartz rock.
MC-19A	In Río Burro Playa 1.5 km above Río Minas. Megacrystic (feldspar) T.L. granite.
MC-19B	Same location. Float melanocratic volcanic. (Magn. susc. = 10).
MC-19C	Same location. Float highly sulphidic volcanic rock with quartz xenoliths.
MC-20	Same location, as MC-14. Strongly foliated T.L. granite with cleaved feldspar megacrysts.
MC-21	7 km east of Dacte in Río Blanco. Compact metaquartzite facies of semi-pelitic unit.
Río San Francisco (near the Gualaceo-Limón road)	
MC-29A-D	Float blocks of epidote - quartz - chlorite rocks, in area of alluvial gold mining.
MC-30	Same location. Spongey pyritic mass (Magn. susc. = 50)

5.3 Ayllón area

5.3.1 Geology outline

This area comprises the western flanks of the Andean Cordillera Real east of Peggy Mine; and drained by the Río Santa Bárbara and its tributaries. The rocks exposed all belong to the semi-pelite unit described previously from the Burro Playa Area to the north; but represent a more easterly extension. The dominant structure is again open folding on sub-horizontal axes with an Andean trend. An earlier phase of tight folding can sometimes be seen, e.g. MC-27A (= Sample FV-CR-618).

The pelites contain frequent white quartz lenses and pods which contain relicts in chlorite, of altered pelite. No exposures of mineralisation were seen but a number of mineralised float samples were collected in the vicinity of extensive old and new alluvial mines near the junction of the Ríos Ayllón and Santa Bárbara. The older, more extensive mines have large volumes of carefully stacked boulders forming retaining walls - a degree of scale and sophistication not seen elsewhere. On the east bank of the Santa Bárbara, approximately 0.5 km downstream from its junction with the Río Ayllón, is an old adit whose portal is now collapsed but beyond which some rotten timbering is visible. The south side of the 30 m open cut leading from the river to the collapsed adit is lined with moss and lichen covered veinstone blocks ($\pm$ 50 tonnes). Fresh surfaces reveal a number of sulphides in the pale cream quartz gangue. It is presumed that this operation led to the attempt to carry in a Mill, parts of which were noted on the approach path. No record of this prospect has been located in the literature; it must be at least ten years old.

Float of chalcopyrite schlieren in pelite, pyrite/quartz veinstone and, 0.75 km upstream quartz-arsenopyrite veinstone in contact with altered andesitic volcanic rock, was collected. The latter sample MC-27A also has visible free gold in the quartz. The area visited is downstream from the Laguna Ayllón which would be a good base to explore the surrounding country. This area is however of classic paramo type with frequent rain and numerous peat bogs. An attempt had previously been made to enter from Dacte, to the N of Peggy Mine, but failed due to the inability of the mules to cross the swampy ground.

5.3.2 Base and Precious metal analytical data (Table 4a, b)

All eight samples assayed carried gold, in each case visible sulphide being also present. Three samples of veinstone from the old adit (MC-25A, B and C) averaged over 300 g/t gold and 130 g/t silver (9 and 4 oz respectively) and appreciable lead & zinc. Significant antimony was also recorded (up to 0.49%). Two samples of pelite with chalcopyrite schlieren assayed 1.59 and 0.68 g/t and a float carrying pyrite-marcasite in quartz gangue 2.19 g/t. The quartz-arsenopyrite vein assayed 5.21 g/t and 2.3% As.

5.3.3 Pan sample data (Table 1)

Nine pan samples were collected in most of which gold was visible. The heavy mineral examination showed, additionally, that all except one sample carried appreciable numbers of scheelite grains. Of the various areas from which pan samples were collected this (Ayllón) area carries the most scheelite and gold

5.3.4 Mineralogical investigations (see Appendix 6 of this Annual Report)

Two ore samples were submitted for polished section examination; native gold was identified in both. MC-25 is an example of the ore stacked at the entrance of the old adit and pyrite and arsenopyrite are common in a quartz gangue. Galena and sphalerite (the latter with inclusions of chalcopyrite) are early and boulangerite ($\text{Pb}_5\text{Sb}_4\text{S}_{11}$) and gold are later crystallising phases. Related bournonite (PbSbCuS_3) occurs as late-stage veinlets. The relation of gold and antimony here may be a useful geochemical indicator.

Sample 27A is from the quartz arsenopyrite-gold float. Detailed examination shows that arsenopyrite is accompanied by minor galena and that the gold postdates both. Probe analysis revealed that the gold in each sample contains approximately 35% silver, i.e. the gold to silver ratio is 2:1, (this is also the bulk ore ratio for the samples 25A, B and C as revealed by the assay data).

As well as polished section and probe investigation of the above two samples MC-27C was examined petrographically (see Appendix 5 of this Annual Report). It has the character of an altered hornblende diorite with appreciable chloritoid and epidote as alteration products of the hornblende, and actinolite, zoisite and sericite after plagioclase. This sample is believed to represent the host rock of the arsenopyrite-quartz-gold vein and the presence of chloritoid may equate with hydrothermal alteration (see Appendix 5 of this Annual Report).

5.3.5 General conclusions

The ore sample results show that polymetallic Cu-Pb-Zn-As-Ag-Au mineralisation exists, probably associated with an intermediate intrusion. The high number of scheelite grains in pan samples probably result from dispersion of scheelite of contact metasomatic origin.

The elevated gold values from the stacked ore pile obviously are of great importance and it would be most interesting to open up the adit to examine the setting of that ore.

The location of gold quartz vein float upstream further enhances the interest of this area, which historically is one of the most often mentioned alluvial areas of the early Spanish records.

Both analysis of native gold and assay of whole ore samples show that ratios in this area are quite different from those at Peggy Mine, with silver to gold equal to 1:2. Another individual character is the associated Antimony.

Table 4a. Ayllón area

Sample	Au (g/t)	Ag (g/t)	Cu%	Pb%	Zn%	Cd%	Sb%	Bi%	As (ppm)	W (ppm)	Sn (ppm)
MC-25A	46.5	24	0.06	0.49	0.68	0.004	0.18	0	9998	15	0
MC-25B	635	246	0.04	1.72	3.07	0.012	0.49	0	22030	5	0
MC-25C	427	128	0.02	0.99	1.52	0.006	0.32	0	9597	11	0
MC-25D											
MC-26A	2.19	0	0	0.01	0.02	0	0.01	0	191	3	6
MC-26B	1.59	1	0.06	0.02	0.04	0	0	0	39	16	13
MC-26C	0.68	1	0.12	0	0.02	0	0	0	23	17	12
MC-27A	5.21	1	0	0	0.02	0	0	0	23258	4	5
MC-27B	(Structural sample)										
MC-27C	(Full analysis)										
MC-28	0.39	14	0.36	0	0.02	0	0	0	88	17	24

Table 4b. Ayllón area

MC-24	Junction of Río Cueva de Gallo with Río Ayllón. Float fresh meta-volcanic with minor sulphide.
MC-25A	Ore piled at entrance of collapsed adit in east bank of Río Ayllón 0.5 km downstream from junction with Río Sta. Bárbara. Quartz vein carrying Pb, Zn, Cu and Fe sulphides and heavily altered, chloritised inclusions of pelite.
MC-25B	
MC-25C	
MC-25D	
MC-26A	30 m upstream from MC-25. Float of white quartz veinstone brecciated with quartz and pyrite.
MC-26B	50 m downstream from MC-25. Float includes silicified pelite with schlieren and 1 mm width veinlets of sulphide, including chalcopyrite.
MC-26C	Same location. Similar sample.
MC-27A	400 m north of Ayllón campsite. Float of pearly-white quartz veinstone with contact to altered, andesitic, volcanic. Veinstone is banded parallel to the contact and contains arsenopyrite and some visible gold.
MC-27B	Same location. Large boulder of pelite exhibiting S ₀ , S ₁ and S ₂ surfaces.
MC-27C	Same location. Float of reasonably fresh andesitic volcanic believed to be equivalent to that in contact with quartz vein carrying gold (27a).
MC-28	

5.4 Minas de Nambija

5.4.1 Geology outline

The Nambija and associated mining camps of Campana, Campanilla and Guaysimi, comprise the most spectacular mining development in Ecuador. Dozens or hundreds of small groups (Sociedades), totalling thousands of people, are working what is often extremely hard ore by usually fairly primitive methods. These may frequently involve uncontrolled blasting, development of huge open stopes, almost complete lack of mechanised ore transportation (95% of all ore is backpacked by Cargadores), grinding by stamp batteries or occasionally Chilenos mills, and separation by mercury. Much of the gold is collected on blankets or in sluice boxes topographically below the main hard rock mines.

Only Nambija was visited, three days being spent during which over ten different mines were entered and a large number of samples collected, some carrying visible gold, usually associated with late quartz healed fractures. The rich ore of the Arco (northern) and Playón (southern) sectors is hosted by a grey-green skarn which frequently has a relict foliation or bedding. However, on the upper part of the southern sector of Nambija (Mapasingue) altered volcanic rock of probably andesite-dacite original composition is cut by quartz veins and shear zones which carry both minor sulphides and some gold. In the lower central part recrystallised grey limestone exists but its relation to the skarn and volcanics was not seen in the field.

The preferred model interprets the bedded rocks as calcareous volcanoclastics surrounding a microdiorite plug and deposited in a volcanic arc - fringing reef environment. This complex was then subject to major N-S fissuring allowing the ingress of metasomatising and mineralising fluids from the calc-alkaline magma chamber accessed by the fissure.

5.4.2 Analytical data (Table 5a, b)

Twenty-two samples of material mined from various parts of the area were assayed for gold and silver. Gold was detected in every sample, silver in only six. The bulk gold to silver ratio is more than 10:1. The highest values were usually from rocks in which visible gold occurs and were from the lower part of Playón and central part of Arco. The latter area is the source of numerous collectors' samples of free gold which are sold individually in a form of market.

5.4.3 Pan sample data (Table 1)

No pan samples were collected as it was believed that they would only represent contamination from the very numerous mining and milling operations.

5.4.4 Mineralogical investigations (see Appendix 6 of this Annual Report)

MC-64C consists almost entirely of grossular garnet with interstitial vein quartz and calcite. Gold was identified, also interstitial to garnet. Sparse disseminated sulphides occur.

MC-65B is similar but has pinkish feldspar in addition to the quartz and calcite, both interstitially and as post-garnet veinlets.

MC-64E is a crystal-rich andesitic tuff partly made over to grossular-rich skarn.

5.4.5 General conclusions

The gold deposition is accompanied by quartz and pink feldspar $\pm$ calcite and generally postdates the skarn development. The host rocks were calcareous volcanoclastics and intermediate subvolcanic bodies forming in an arc-fringing reef environment. The ore sample assays and analysis of gold grains show this occurrence to be extremely poor in silver, a characteristic not shared by any other rock data from this study and by only a few partial analyses of pan gold (see Appendix 6 in this Annual Report).

Table 5a. Nambija mines

Sample	Au (g/t)	Ag (g/t)
MC-60A	0.02	0
MC-60B	0.05	0
MC-60C	5.75	2
MC-61	0.03	0
MC-62A	27.4	0
MC-62B	0.12	0
MC-63A	0.05	0
MC-63B	0.08	0
MC-63C	0.62	0
MC-64	0.36	0
MC-64C	145	14
MC-64D	442	17
MC-64E	0.43	0
MC-65A	2.02	0
MC-65B	5.97	0
MC-66A	99.5	3
MC-66B	1.65	0
MC-66C	0.13	0
MC-67	0.11	2
MC-68	0.03	0
MC-69	0.16	0
MC-90	0.98	5

Table 5b. Nambija mines

MC-60A	Mapasingue Alto (Abandoned quarries on top of ridge). Quartz veins with open texture and minor chalcopyrite.
MC-60B	Same location. Altered and propylitized volcanic.
MC-60C	Same location. Calc-silicate matrix (skarn) with Calcite, Quartz and Chalcopyrite.
MC-61	Volcanic cut by chlorite/pyrite veinlets (Sociedad Velasquez).
MC-62A	Volcanic hosting quartz/calcite veinlets (Sociedad Benitas).
MC-62B	Epidote rich skarn with quartz - calcite - chalcopyrite (Sociedad Benitas).
MC-63A	Volcanoclastic skarn (+10 meters, another adit).
MC-63B	Same location. Volcanoclastic skarn.
MC-63C	Same location. Volcanoclastic skarn.
MC-64	Bedded skarnified volcanoclastics or sediments. Epidote and garnet prominent; many fractures. Visible gold in some samples (Playón main mine).
MC-64C	
MC-64D	
MC-64E	
MC-65A	Calc-silicates with chlorite, epidote (Arco Zone).
MC-65B	Pink feldspar and sometimes visible gold (Arco Zone).
MC-66A	Skarn cut by quartz veins sometimes carrying prominent gold (Golden West Mine).
MC-66B	
MC-66C	
MC-67	Volcanics cut by oxidised veinlets (Mapasingue Castillo).
MC-68	Skarnified volcanoclastic? with Adularia (Mapasingue Tocayos).
MC-69	Sulphidic matrix hard breccia (Campana Mine).
MC-90	Dense banded pyrite/chlorite rock (Campana Mine area).

5.5 Piuntza and Chinapintza primary gold prospects

5.5.1 Geology outline

These two prospects, like Nambija and its nearby skarns occur within the Sub-Andean Belt of southern Ecuador, east of the continental watershed. The Sub-Andean Belt is generally interpreted as a complex volcano-sedimentary terrain dominated by calc-alkaline arc-type magmatism. The typical rock is a granodiorite of batholithic proportions within which metasedimentary rafts and roof pendants are common as well as co-magmatic volcanic piles of andesite-dacite composition.

Piuntza and Chinapintza lie 13 km west and 23 km east of Nambija respectively and are approached via Zamora. They are both located in areas for long known for alluvial gold but no reference to their geology was seen except for a company report describing Piuntza as comprised of conglomerate.

Unlike Nambija however the mineralisation at these two prospects is not associated with calc-silicate skarn formation. At both Piuntza and Chinapintza the major association is with 'young' quartz-feldspar porphyry intrusions. The observed mineralisation occurs as veins and breccias and in general is of epithermal nature.

The two differ in the level of erosion:

(1) Piuntza is mainly cloaked with the remains of a lava and pyroclastic pile of, sometimes pumiceous, lapilli tuff and tuff, into which the porphyry body is intruded. In the central, highest part it is probable that the breccia is intrusive but laterally, bedding and, conclusively, the presence of accretionary lapilli; betray the extrusive character. The central breccia is auriferous and extensive trenches and shallow excavations show that surface mining has been carried out in the past. As well as occurring in the breccia, gold is associated with a network of quartz-sulphide veinlets in the upper part of the porphyry body.

(2) Chinapintza, probably a much larger prospect, exhibits no extrusive phase on the traverse made - the country rock is a coarse-grained granodiorite - extensively propylitized and increasingly cut by quartz veins and porphyry dykes as the mining area is approached. The primary ores (revealed by very recent artisanal hard rock mining) are both exo- and endo-contact veins and breccias related to a quartz-porphyry body only seen in adits.

In July 1988 there were only a few stamp mills on site but it appeared that the area was seeing the commencement of a rush of quite large dimensions. Further up hill, not visited, the ores worked were reported to be a quartz stockwork but at the site visited the rich ore appeared to be in sub-parallel near vertical oxidised veins. Some adits have penetrated beyond the oxidised zone and reveal that lead, zinc and copper sulphides are prominent, filling interstices of a breccia within the porphyry body.

5.5.2 Base and Precious metal analytical data (Table 6a, b)

Eleven of the twelve samples submitted from Piuntza assayed trace or more gold with MC-55, an example of the small-scale veining cutting the upper part of the porphyry, giving 5.54 g/t. An example of the intrusive breccia, which pans gold, gave 7.32 g/t.

At Chinapintza traces of gold, up to 0.11 g/t, were obtained from samples of porphyry dykes exposed in the approach road. A sample (MC-77) from a heavily oxidised friable vein pointed out as being very rich gave 363 g/t gold (11 oz) and 197 g/t silver. A similar sample (MC-79A) from 400m below gave 11 g/t gold and 250 g/t silver.

Four samples (MC-78) of the fresh, sulphide breccia filling within the porphyry body were assayed and averaged 0.35 g/t gold, 37 g/t silver and 2.75% zinc with minor copper and lead. With the exception of MC-77 the remaining (seven) samples show a silver to gold ratio of 25-100:1.

5.5.3 Pan sample data (Table 1)

Two samples were taken at Piuntza and none at Chinapintza. P34 is a gold concentrate panned from the auriferous breccia and P35 from the headwaters of the Río Piuntza. The percent silver in both was very similar.

5.5.4 Mineralogical investigations (see Appendix 6 in this Annual Report)

One sample from Piuntza was examined in reflected and transmitted light (MC-56A). The quartz and feldspar-phyric porphyry shows slight alteration to white mica and clay minerals and is cut by a 1 mm quartz vein containing minor pyrite and sphalerite. Full major and trace element analytical data is also available for this sample which is potash rich, probably as a result of potassium metasomation at a late or post magnetic stage (Table 11).

Several samples of MC-78 were submitted for detailed examination. The host rock is a feldspar-phyric dacite which has suffered argillic alteration and silicification. Sphalerite is the most prominent interstice fill and contains inclusions of argentiferous galena, pyrite, pyrrhotite and chalcopyrite.

Two further slides of MC-78 were submitted to a separate worker (Ref 3) and a detailed examination requested for discrete silver minerals; again, it was concluded that silver was held in galena.

5.5.5 General conclusions

The mineralisation at Piuntza and Chinapintza is of epithermal style and relates to the emplacement of high-level porphyry stocks of dacitic composition.

At Piuntza the volcanic pile, including pyroclastics, dominates the surrounds even though the porphyry plug is just being unroofed. At Chinapintza the relationship between country rock, altered country rock and porphyry dykes, to the main mineralisation, is clearly exhibited. The relief is such that zonation from high level quartz stockworks down to larger veins and sulphide filled breccias is believed to be demonstrable and the area most suitable for a case-study

The apparently larger size, greater state of dissection and indications of higher grade make Chinapintza a good economic prospect at the present level of understanding. This conclusion is supported by the very large number of informal miners converging on it.

Table 6a. Chinapintza and Piuntza samples

Sample	Au (g/t)	Ag (g/t)	Cu%	Pb%	Zn%	Cd%	Sb%	Bi%	As (ppm)	W (ppm)	Sn (ppm)
Chinapintza prospect area											
MC-70											
MC-71	0.01	0									
MC-73A	0.01	0									
MC-73B	0.01	0									
MC-74	0.02	0									
MC-75	0.02	2									
MC-76	0.11	12									
MC-77	363	197									
MC-78A	0.48	79	0.04	0.09	3.49	0.028	0	0	342	13	8
MC-78B	0.54	32	0.04	0.11	5.27	0.041	0	0	196	0	11
MC-78C	0.06	2	0	0.02	0.52	0.004	0	0	60	19	8
MC-78D	0.32	35	0.03	0.1	1.73	0.024	0	0	330	16	10
MC-79A	11	250									
MC-79B	0.04										
Piuntza prospect											
MC-54A	0.01	0									
MC-54B	0.19	9									
MC-54C	0.03	0									
MC-54D	0.07	2									
MC-55	5.54	3									
MC-56A	Analysis										
MC-56B	0.17	16									
MC-56C	7.32	38									
MC-56D	0.05	4									
MC-57A	0.05	0									
MC-57B	0.02	2									
MC-58	0.03	0									
MC-59	0	0									

Table 6b. Chinapintza and Piuntza samples

Chinapintza prospect	
MC-70	Road Bridge (site of age determination sample). Hornblende granodiorite with narrow sulphidic veins with marginal alteration.
MC-71	Sheared and propylitized granodiorite.
MC-73A	Same location. Quartz/oxide vein cutting granodiorite.
MC-73B	Near first settlement. Quartz/oxide vein cutting granodiorite.
MC-74	1 Km on mule track to prospect. Pale cream porphyry dyke.
MC-75	0.5 Km further east. Similar with late silicification.
MC-76	+ 200 m. Similar sample.
MC-77	Chinapintza mining area. Heavily oxidised quartz/oxide vein.
MC-78A	Chinapintza mining area. Fresh sulphide ore samples from adit which has penetrated a brecciated quartz feldspar porphyry body. Sulphides are mainly sphalerite, galena and pyrite with minor chalcopyrite.
MC-78B	
MC-78C	
MC-78D	
MC-79A	SW sector of mining area. Oxidised veinstone.
MC-79B	SW sector of mining area. 5 metres northeast. Similar vein.
MC-70	
Piuntza prospect	
MC-54A	Volcanic breccia with pumice clasts and sulphidic matrix.
MC-54B	Similar with chlorite sealing fracture.
MC-54C	Fresh, blue-grey coloured sulphidic matrixed breccia. Clasts include quartz-feldspar porphyry.
MC-54D	Similar to above, when crushed gives gold colours.
MC-55	Quartz feldspar porphyry with sub-mm sulphidic veinlets.
MC-56A	Fresh quartz feldspar porphyry.
MC-56B	Metasedimentary clast in porphyry - sulphide impregnation.
MC-56C	Mineralised volcanic breccia.
MC-56D	Fresh quartz-feldspar porphyry.
MC-57A	Float sample of extrusive breccia.
MC-57B	Tuff with well-formed accretionary lapilli.
MC-58	Quartz pyrite vein.
MC-59	Quartz, chlorite, epidote fault rock.

5.6 Palanda and Río Mayo area

5.6.1 Geology outline

These areas represent part of the southern Ecuadorean Sub-Andean Batholith and comprise a road section through Palanda on the highway between Loja and Zumba and an area near Río Mayo east of Zumba on the foot track to the Los Planes gold prospect (see next section).

Two localities of interest were examined in road cuts near Palanda, in one very extensive propylitization occurs accompanying deformation in a fault or shear zone. The second area exposes a subparallel swarm of 1-2 mm quartz-pyrite veinlets with narrow propylitized margins. The host in both cases is granodiorite and no evidence of, e.g. porphyry intrusives was seen.

Immediately east of Río Mayo very narrow copper veining cutting granodiorite was noted and on the old road leading west to La Cruz andesitic-dacitic volcanics are associated with small exposures of epidote-quartz-magnetite rock of skarn affinity.

5.6.2 Base and Precious metal analytical data (Table 7a, b)

The six samples assayed from the above areas gave one significant result - the copper veinlet assayed 1.12 g/t gold (MC-33B). The three samples from the heavily altered shear zone on the Palanda road assayed one trace, but another examination of this occurrence is warranted.

5.6.3 Mineralogical investigations (see Appendix 5 in this Annual Report)

No polished section reflected light or probe work was carried out on rocks from this area. One sample from the Palanda road shear zone (MC-46C) was examined petrographically and confirms the field observation, that the alteration minerals are quartz, epidote, calcite and chlorite with some pyrite.

5.6.4 General conclusions

The exposures examined on the Palanda road show extensive alteration in places but grab samples assayed do not indicate that the alteration accompanies economic mineralisation. The one sample with base-metal sulphide did assay over 1 g/t gold, from Río Mayo.

Table 7a. Palanda-Río Mayo

Sample	Au (g/t)	Ag (g/t)	Cu%	Pb%	Zn%	Cd%	Sb%	Bi%	As (ppm)	W (ppm)	Sn (ppm)
MC-32	0.01	0									
MC-46A	0	0									
MC-46B	0.02	0									
MC-46C	0	0									
MC-33A											
MC-33B	1.12	2	0.18	0	0	0	0	0	25	3	0
MC-34	0.05	0	0.04	0	0	0	0	0	40	5	12
MC-45	0.01	0									
MC-92	0.04	0									

Table 7b. Palanda-Río Mayo

MC-32	Palanda-Zumba road. Young volcanic with epidote/chlorite veins.
MC-46A	
MC-46B	Main road south of Palanda. Silicified, chloritised, sheared granodiorite.
MC-46C	
MC-33A	South bank of Río Mayo. Fresh sub-andean granodiorite.
MC-33B	Same location. Granodiorite cut by 1 mm copper vein.
MC-34	Same location. Float metavolcanic with disseminated pyrrhotite.
MC-45	Old road west of Río Mayo. Altered volcanic rock with magnetite and epidote.
MC-92	Unknown locality; from barkeeper at Palanda. Is diorite with prominent pyrite.

5.7 Los Planes (Sachacuri) and adjacent traverse

5.7.1 Geology outline

The Los Planes gold prospect consists of a series of narrow quartz veins and quartz stockworks hosted by a series of strongly weathered and argillitised tuffs and dense andesite lavas. The area of interest is part of a much larger area underlain by andesite-dacite lavas and pyroclastics probably forming a volcanic massif consanguineous with the granodiorite batholith immediately to the west, which is also part of the sub-Andean zone.

The prospect area shows evidence of old mining operations with overgrown water channels and some shallow excavations. It is at present being explored by Cyprus Minerals, and in July 1988 some scout drilling was being carried out.

Although two days were spent on the prospect no clear-cut structure emerged - there appears to be a quite large number of veins up to 10 cm in width and some wider areas of quartz stockworks but no pattern was discovered. Some of the veins, especially in the andesite lavas carry pyrite etc.

A traverse from the prospect area was made northwards to Río Afiladeras, crossing andesitic volcanics and pyroclastics all the way. Large blocks of sugary white sandstone (Hollín Fm.?) were observed but their relationship to the volcanics not ascertained. The return traverse crossed a number of volcanic enclaves within the granodiorite and streams draining the volcanic massif were sampled.

5.7.2 Analytical data (Table 8a, b)

Twelve samples of veins were collected, mostly from sites pointed out by the prospects' manager. All except one gave values of gold above 0.2 g/t. One sample, MC-35A, from a dense quartz stockwork, assayed 233 g/t gold and 62 g/t silver, the next highest value was 3.02 g/t gold. Two samples of sulphide rich pyroclastics from Río Afiladeras were assayed with no significant result.

5.7.3 Pan sample data (Table 1)

Seven pan samples were collected, two from below the prospect, one of these (P23) carries scheelite, gold being seen in both. Of the other five samples gold was seen in only two and no scheelite observed.

5.7.4 Mineralogical investigations

No study was undertaken of rocks from this area apart from assay. A gold concentrate from the outcrops equivalent to MC-35A was panned from a crushed sample and is listed as pan sample P47 and many small grains reported. No data on the silver-gold ratio was however reported (see Appendix 6 in this Annual Report).

5.7.5 General conclusions

The Los Planes prospect consists of a wide area of quartz veins and stockworks hosted by andesitic-dacitic lavas and pyroclasts. Gold values obtained are generally low with one exception. The style is fairly high level epithermal and it could well be expected that larger veins exist at depth, probably with associated sulphides. The regional context is of emplacement associated with calc-alkaline volcanic piles with a batholithic substrate.

Table 8a. Los Planes and Río Afiladeras

Sample	Au (g/t)	Ag (g/t)
MC-35A	233	62
MC-35B	1.48	3
MC-35C	0.68	1
MC-35D	0.24	0
MC-36	0.24	1
MC-37	0.21	0
MC-38	0.35	2
MC-39	0.39	10
MC-40A	0.02	0
MC-40B	3.02	4
MC-41	0.55	3
MC-42	0.28	1
MC-43A	0.03	0
MC-43B	0	0
MC-44A	0	0
MC-44B	0.01	0

Table 8b. Los Planes and Río Afiladeras

MC-35A	Quartz vein in weathered pale cream tuffs 200 m below camp. Said to contain gold.
MC-35B	100 m east of 35A. Similar rock.
MC-35C	Near drill site. Silicified tuff.
MC-35D	Near drill site. Quartz stockwork.
MC-36	Above drill site. Quartz-sulphide vein cutting very hard tuff.
MC-37	50 m downhill. Quartz-sulphide vein cutting andesite.
MC-38	300 m uphill. Silicified volcanics with sulphide.
MC-39	200 m uphill. Quartz vein.
MC-40A	Above drill site. Quartz vein with sulphides cutting andesite.
MC-40B	Same location. Similar sample.
MC-41	100 m uphill past waterfall. Similar sample.
MC-42	50 m upstream. Similar sample.
MC-43A	Río San Francisco Sachacuri Float mineralised tuffs.
MC-43B	Same location. Quartz-pyrite vein.
MC-44A	Río Afiladeras. Lapilli tuffs with disseminated sulphides.
MC-44B	Río Afiladeras. Bedded tuffs and lapilli tuffs (extrusive).

5.8 Loma del Inca, Loja and Malacatos granites

5.8.1 Geology outline

These are three separate granite areas south of Saraguro which are equated with the Tres Lagunas Granite (TLG) Suite as exposed at Peggy Mine etc. All three are emplaced in metamorphic country rock correlated with the Loja semi-pelite unit exposed to the east of the Baños Front zone of deformation at, e.g. Peggy Mine. However, there is some uncertainty whether the Baños Front extends this far south although the Las Aradas Fault Zone could be an expression thereof.

The Malacatos granite was examined at its southern outcrop 5 km north of Malacatos Town. In outcrop it has a typical TLG appearance - being a biotite feldspar-megacrystic blue quartz granite with quite numerous tourmaline patches and narrow crosscutting veinlets. Occasional muscovite rich portions have a greisen appearance.

Both the Loma del Inca granite (14 km SW of Malacatos) and the Loja granite (16 km NNW of Loja on the new road to Saraguro) have a different character to most other occurrences of the TLG, in that they are undeformed and clearly crosscut both the D1 and D2 fabric of their host rock, i.e. are post tectonic. Both have well exposed contact relations and pass marginally into pegmatites and quartz-feldspar-tourmaline veins. The country rock is often recrystallized to a muscovite rich rock adjacent to contacts of these veins and pegmatites - a form of greisenization. However, despite careful examination no indication of oxide or sulphide minerals was observed in the pegmatites, veins or greisens.

5.8.2 Analytical data (Table 9a, b)

Five samples of tourmaline and/or muscovite bearing granite and greisen from the Malacatos outcrop were analysed for tin and tungsten but no significant values obtained.

Eight samples of marginal and vein facies of the post tectonic granites gave maximum values of 23 ppm tin and 32 ppm tungsten, too low to excite much interest.

5.8.3 Pan sample data (Table 1)

Six samples were panned but neither cassiterite nor gold was identified. The Malacatos pan samples contained some scheelite.

5.8.4 Mineralogical investigations

The lack of any indications of mineralisation did not warrant preparation of polished sections for reflected light work.

Three samples of the Malacatos tourmaline bearing granite were examined petrographically (MC-50A, 50C & 52A) and observations given in Ref 2. No ore minerals were noted.

5.8.5 General conclusions

Two of these three biotite, muscovite-tourmaline granite occurrences are small post tectonic stocks with marginal veins and pegmatites intruding and altering the country rock to small scale barren greisens.

The third, (Malacatos) is a typical cataclased TLG.

All the available data indicates that these granites have a low potential for economic mineralisation.

The age relations deduced here indicate that there are probably both an earlier (syntectonic) and later (post tectonic) phase of two-mica tourmaline granites.

Table 9a. Loma del Inca, Loja and Malacatos granites

Sample	Au (g/t)	Ag (g/t)	Sn (ppm)	W (ppm)	Analysis
MC-47A			16	32	
MC-47B			14	13	
MC-47C			5	2	
MC-47D			23	11	
MC-48			6	4	A
MC-49	0.01	0			
MC-50A			1	0	A
MC-50B			4	2	
MC-50C			5	0	
MC-51			1	0	
MC-52			11	0	
MC-80			5	0	A
MC-81A			14	0	
MC-81B			10	17	

Table 9b. Loma del Inca, Loja and Malacatos granites

North contact zone of Loma del Inca granite	
MC-47A	Quartz-feldspar-tourmaline rock? Pegmatite.
MC-47B	Quartz-tourmaline exo-contact vein.
MC-47C	Quartz-sericite-feldspar-tourmaline vein.
MC-47D	Banded quartz-tourmaline-muscovite rock.
Central part of outcrop	
MC-48	Biotite granite.
MC-49	Quartz veinstone with later brecciation and oxide impregnation.
North margin of Malacatos basin	
MC-50A	Foliated biotite granite with tourmaline as clots or mm width veinlets.
MC-50B	
MC-50C	
MC-51	Quartz-feldspar-muscovite pegmatite with tourmaline.
MC-52	Biotite-quartz-muscovite greisen.
Post tectonic pegmatitic granite on new road north of Loja	
MC-80	Pegmatitic biotite granite-two grain sizes.
MC-81A	Muscovite rich pegmatitic granite with ore.
MC-81B	Tourmaline. Medium to fine grained quartz-muscovite rocks.

5.9 Espiritu Playa and Saraguro areas

5.9.1 Geology outline

10 km east of Saraguro previous work had located tin and tungsten minerals in pan concentrates. The area marked as TLG on the CR 1:250000 scale map was visited. This entire area exposes either young volcanics or young microgranodiorites. Float in streams indicates that older rocks probably outcrop on the continental divide further west, but were not reached.

The Espiritu Playa-Pulca Urco area is located 45 km NNE along strike from the Saraguro tin anomaly and 24 km SSW of Peggy Mine, being on the southern extension of the Baños Front. The area lies in the headwaters of the easterly draining Río Chauli - the nearest town being Gima, 15 km to the north west. On the approach road/track TLG alternates with quartz-sericite schists and both are associated with numerous white quartz veins, some carrying sulphide or tourmaline. Small areas of greisen, quartz-muscovite-tourmaline rock occur on the track descending into the valley of the Río Chauli.

In the valley over a width of at least 4 km coarse grained biotite granite of TLG type is exposed in the main and side streams. It is less tectonised in eastern outcrops and deformation increases westwards towards the 'Baños Front'. Some small-scale alluvial gold workings are known but little indication of mineralisation was observed with the exception of zones of pyrite impregnated granite associated with small shears. Younger granodioritic intrusions may be the cause of this occurrence. There is evidence of large-scale boulder slides on both sides of the upper reaches of the Chauli.

5.9.2 Analytical data (Table 10a, b)

One sample of granodiorite (MC-B2) from the Saraguro area was analysed for major and trace elements (Table 11). Five samples from Espiritu Playa were assayed including two of the pyrite impregnated TLG (MC-88A, B and 89). No gold was detected except for a trace in a quartz-pyrite vein sample (MC-83A). A further five samples were analysed for tin and tungsten and in one (MC-85, identified as greisenized in the field) a value of 63 ppm tin was recorded, the remaining values were all low.

5.9.3 Pan sample data (Table 1)

Five pan samples were collected in streams east of Saraguro. In the most northerly (P40) cassiterite was identified and quoted as 'common'. This sample also contained considerable scheelite. This site had float gneissic granite boulders unlike the other four which only exhibited young tuff and microgranodiorite. The anomalous stream is not that marked on the CR 1: 250000 but to the north – the Río Pichanal (GR-064-984).

Seven samples from the Espiritu Playa area contained neither scheelite, gold or cassiterite.

5.9.4 Mineralogical investigations

No rock samples were examined in reflected light. Petrographic examination of MC-82 (microgranodiorite from west of Saraguro) and MC-93 (a biotite and muscovite granite of the TLG association) was carried out as part of a comparative study of granite types (see Appendix 5 of this Annual Report).

5.9.5 General conclusions

The tin (cassiterite) anomaly east of Saraguro was confirmed but the source area not traversed. As previously reported also, tungsten, as the phase scheelite, is also prominent in the same stream. However, in the Ayllón area scheelite is also common in the stream sediments and an origin separate from that for tin must be considered likely for some or all of the scheelite. Scheelite (CaWO_4) is commonly associated with 'I' type granites particularly in skarn deposits. Some of the largest tungsten deposits consist of scheelite in skarn.

The granite of the Espiritu Playa area is a TLG type and is progressively less deformed the farther east it is traversed. No cassiterite was found in any of the pan samples but one greisen sample gave a value of 62 ppm SN which, while definitely above background is insufficient evidence alone for assuming the presence of a prospective area.

Evidence for gold mineralisation in the area is confined to the trace assayed in one quartz-pyrite vein sample.

Table 10a. Espiritu Playa and Saraguro areas

Sample	Au (g/t)	Ag (g/t)	Sn (ppm)	W (ppm)	Analysis
MC-83A	0.01	0			
MC-83B			3	0	
MC-84	0	5			
MC-85			63	6	
MC-86			2	7	
MC-87			8	4	
MC-88A	0	5			
MC-88B	0	5			
MC-89	0	5			
MC-93			7	3	A
MC-82			0	0	A

Table 10b. Espiritu Playa and Saraguro areas

MC-83A	Mule track from Moriré to Espiritu Playa. Quartz-pyrite vein in schist.
MC-83B	Similar location. Quartz-tourmaline vein in schist.
MC-84	Similar location. Massive grey quartz with pyrite.
MC-85	Muscovite and tourmaline rich marginal facies of biotite granite - greisen.
MC-86	South bank Río Chauli. Altered muscovite-quartz rock? Greisen.
MC-87	Same location, similar sample.
MC-88A	0.5 km west of 87. Pyrite and sericite associated with net veined and fractured granite.
MC-88B	Same location. Weakly pyritic shear zone in granite.
MC-89	2.0 km west of 88. Similar sample to 88A.
MC-93	Espiritu Playa bridge. Fresh blue quartz biotite granite.
MC-82	

6. GEOCHEMISTRY OF A SUITE OF GRANITES AND SILICIC VOLCANICS AS AN AID TO THEIR CLASSIFICATION

6.1 Introduction

Investigations by the BGS/INEMIN team in Ecuador (Litherland, 1988) had previously proposed that a zone of granites known as the Tres Lagunas Granite suite (TLG) were unlike typical Andean 'I' types. The strongly deformed nature of these granites together with their two-mica character, lack of hornblende and reported association with tin and tungsten lead to the conclusion that they could be 'S' Type collisional granites which in some parts of the world, e.g. SE Asia, host very important economic concentrations of tin and tungsten.

The present investigation tested these proposals in the following ways:

- (a) Careful examinations of outcrop and selection of samples for tin and tungsten assay.
- (b) Collection of heavy mineral pan samples from streams draining granite outcrops - for cassiterite identification.
- (c) Petrographic examination of thin sections - to determine the characteristic mineral suite present.
- (d) Major and trace analysis of a suite of typical granites in order to compare the results with data from elsewhere.

The results of (a) and (b) are given in earlier parts of this report, and in general give a very unfavourable impression of the tin and tungsten potential of the Tres Lagunas Granite suite. The petrographic study (see Appendix 5 in this Annual Report) concludes that the granites are of 'S' type. The remainder of this section introduces and provides some interpretation of the analyses recently completed.

6.2 The suite analysed

Eleven examples of TLG were analysed, eight of which were selected from those collected in 1988 and three are from a suite of samples submitted previously by Dr. Aspden.

In addition, five samples of 'I' type intrusives and three of recent silicic volcanics were analysed for comparative purposes. The samples analysed are listed and results given in Table 11.

Table 11a. Ecuador granites and silicic volcanics

	T	T	T	T	T	T	T	T	T	T	T	A	A	A	A	A	V	V	V
	MC-8	MC-11	MC-14	MC-15B	MC-48	MC-50A	MC-80	MC-93	MC-94	MC-95	MC-96	MC-27C	MC-31	MC-56A	MC-72	MC-82	MC-97	MC-98	MC-99
SiO ₂	72.03	76.09	70.06	76.16	72.61	67.67	74.12	69.52	69.10	72.32	68.43	58.05	70.37	68.90	61.32	63.17	70.94	64.71	61.86
Al ₂ O ₃	13.06	12.97	13.59	12.25	12.97	14.76	14.69	14.61	13.61	13.31	13.41	18.21	16.48	17.15	16.78	16.08	13.83	15.81	15.45
TiO ₂	0.55	0.06	0.55	0.17	0.57	0.58	0.12	0.56	0.75	0.45	0.83	0.71	0.16	0.37	0.48	0.70	0.17	0.53	0.58
Fe ₂ O ₃	0.97	0.41	1.07	1.05	1.36	1.00	0.16	0.91	1.09	0.75	1.64	1.86	0.79	1.44	3.41	2.03	0.51	3.32	3.54
FeO	2.48	0.50	2.52	0.57	2.28	3.34	0.86	2.77	3.54	2.37	3.77	3.27	1.06	0.43	2.17	3.09	0.90	1.81	2.30
MgO	1.10	0.09	1.35	0.20	1.15	2.07	0.25	1.02	1.94	0.91	1.52	3.78	0.64	0.54	1.67	2.60	0.35	2.54	3.47
CaO	1.74	0.19	1.60	0.06	0.56	3.27	1.31	1.62	1.63	1.21	2.26	6.84	3.34	0.04	5.37	4.82	1.79	4.88	5.62
Na ₂ O	2.53	3.03	3.53	2.75	3.07	3.31	3.87	2.82	2.28	2.71	2.42	3.89	4.50	0.25	3.83	3.84	4.09	4.19	3.86
K ₂ O	4.02	5.70	3.08	5.56	3.33	2.23	4.13	4.21	3.53	4.42	3.24	0.70	2.09	8.07	3.28	3.16	2.45	1.65	1.46
MnO	0.09	0.01	0.04	0.01	0.07	0.08	0.02	0.06	0.11	0.08	0.10	0.70	0.07	0.00	0.13	0.12	0.08	0.08	0.09
P ₂ O ₅	0.22	0.12	0.16	0.06	0.07	0.19	0.06	0.16	0.16	0.12	0.25	0.10	0.09	0.12	0.22	0.22	0.08	0.12	0.11
LOI	1.00	0.50	1.88	0.93	1.33	0.86	0.25	1.08	1.39	0.88	1.35	2.04	0.28	2.37	0.80	0.60	4.37	0.10	1.10
Total	99.79	99.67	99.43	99.77	99.37	99.36	99.84	99.34	99.13	99.53	99.22	100.15	99.87	99.68	99.46	100.43	99.56	99.74	99.44
Qtz	35.81	36.22	31.42	38.62	38.26	28.28	32.20	30.86	34.31	34.60	33.55	11.85	27.81	36.00	14.19	18.06	33.14	20.97	18.12
C	1.91	1.76	1.92	1.74	3.47	1.41	1.62	2.85	3.46	2.16	2.41	4.14	0.96	8.22	19.39	12.77	1.39	9.75	8.63
Or	23.76	33.69	18.20	32.86	19.68	13.18	24.41	24.88	20.86	26.12	19.15	32.91	12.35	47.70	32.41	32.49	14.48	35.45	32.66
Ab	21.41	25.64	29.87	23.27	25.97	28.01	32.74	23.86	19.29	22.93	20.48	30.17	38.07	2.12	18.91	20.27	34.61	19.46	20.52
An	7.20	0.16	6.89	0.50	2.32	14.98	6.11	6.99	7.04	5.22	9.58	2.50	15.98	1.34	4.97	1.79	8.36	3.09	5.20
Hy	5.75	0.72	6.27	1.38	5.12	9.65	1.91	6.06	9.40	5.40	8.17	11.64	2.75	0.31	2.43	8.67	1.97	4.90	6.72
Mt	1.41	0.59	1.55	0.10	1.97	1.45	0.23	1.32	1.58	1.09	2.38	2.70	1.15	1.22	4.94	2.94	0.74	4.56	5.13
Il	1.04	0.11	1.04	0.32	1.08	1.10	0.23	1.06	1.42	0.85	1.58	1.35	0.30	0.70	0.91	1.33	0.32	1.01	1.10
Hap	0.52	0.28	0.38	0.14	0.17	0.45	0.14	0.38	0.38	0.28	0.59	0.24	0.21	0.28	0.52	0.52	0.19	0.28	0.26
Hm																		0.18	
Nb	15.00	4.00	10.00	7.00	10.00	8.00	6.00	14.00	13.00	13.00	16.00	3.00	12.00	4.00	6.00	9.00	4.00	6.00	3.00
Rb	150.00	150.00	120.00	146.00	141.00	88.00	114.00	191.00	142.00	206.00	114.00	13.00	95.00	235.00	111.00	77.00	54.00	36.00	33.00
Sn	5.00	9.00	8.00	6.00	6.00	1.00	5.00	7.00	7.00	6.00	5.00	1.00	3.00	2.00	2.00	1.00	1.00	2.00	1.00
Sr	135.00	76.00	111.00	92.00	125.00	176.00	206.00	93.00	128.00	84.00	165.00	655.00	1338.00	118.00	534.00	529.00	302.00	447.00	448.00
Th	9.00	3.00	8.00	3.00	12.00	1.00	5.00	13.00	7.00	16.00	13.00	3.00	4.00	13.00	8.00	13.00	4.00	5.00	10.00
U	7.00	7.00	2.00	1.00	4.00	2.00	4.00	6.00	3.00	8.00	4.00	1.00	3.00	2.00	3.00	4.00	4.00	2.00	1.00
W	1.00	2.00	1.00	1.00	4.00	1.00	1.00	3.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Zr	168.00	53.00	184.00	27.00	215.00	226.00	53.00	199.00	218.00	175.00	302.00	81.00	98.00	87.00	103.00	150.00	125.00	101.00	86.00
Ba	795.00	223.00	541.00	551.00	763.00	335.00	544.00	681.00	967.00	551.00	791.00	164.00	2449.00	1164.00	1156.00	830.00	984.00	757.00	684.00
Ta	<2.00	4.00	3.00	2.00	5.00	5.00	4.00	<2.00	7.00	4.00	4.00	<2.00	3.00	<2.00	4.00	<2.00	2.00	4.00	3.00
Y	39.00	14.00	34.00	23.00	22.00	22.00	21.00	56.00	34.00	39.00	77.00	14.00	6.00	9.00	26.00	20.00	11.00	7.00	11.00
Rb/Sr	1.11	1.97	1.08	1.59	1.13	0.50	0.55	2.05	1.11	2.45	0.69	0.02	0.07	2.00	0.21	0.15	0.18	0.08	0.07
D.I.	80.98	95.55	79.49	94.75	83.91	69.47	89.35	79.60	74.46	83.55	73.18	74.93	78.23	85.82	65.51	70.82	82.23	75.88	71.30

Table 11b. Location and description of granite and silicic volcanic samples analysed for major and trace elements

Tres Lagunas Granite Suite (T)		
MC-8	Immediately below Peggy Mine. Coarse-grained feldspar megacrystic biotite granite.	
MC-11	Between Río Huigra and Río Tres Lagunas, east of Principal. Moderately deformed biotite granite with prominent muscovite up to 3 mm.	
MC-14	100 meters above junction of Río Minas and Río Burro Playa. Blue quartz granite with very marked stretching in subhorizontal direction.	
MC-15B	100 meters below same junction. Blue quartz granite, foliated.	
MC-48	Biotite, muscovite granite at Loma del Inca, southwest of Malacatos. This outcrop is hardly tectonised and has Tourmaline-muscovite rich exo-contact veining. (i.e. is post tectonic).	
MC-50A	North part of Malacatos Basin. Biotite granite, strongly foliated, carries tourmaline.	
MC-80	North of Loja, South of San José Pluton. Post tectonic muscovite rich granite and granite pegmatite, cutting quartz-rich gneisses and greenschists.	
MC-93	Typical granite from near Espíritu Playa footbridge.	
MC-94	= CRFV-498	Samples examined by J. Dangerfield and reported on in Min & Pet Rept. No WG/88/17R.
MC-95	= CRFV-330	
MC-96	= CRFV-223	
Andean Suite (A) (Presumed 'T' Types)		
MC-27C	Float boulder of volcanic rock in Río Ayllón. (Associated with gold?).	
MC-31	Biotite - muscovite micro-granite dyke cutting Tampanchi ultrabasic.	
MC-72	Hornblende microgranodiorite - Río Nambija.	
MC-56A	Quartz Feldspar porphyry - Piuntza prospect.	
MC-82	Biotite - hornblende microgranodiorite east of Saraguro.	
Young Volcanics North of Quito		
MC-97	White pumice clasts from quarried horizon.	Lithics from surrounding area
MC-98	Glassy matrix andesite.	
MC-99	Microdiorite	

6.3 Preliminary interpretation

To facilitate interpretation of the geochemical data, four variation diagrams have been used:

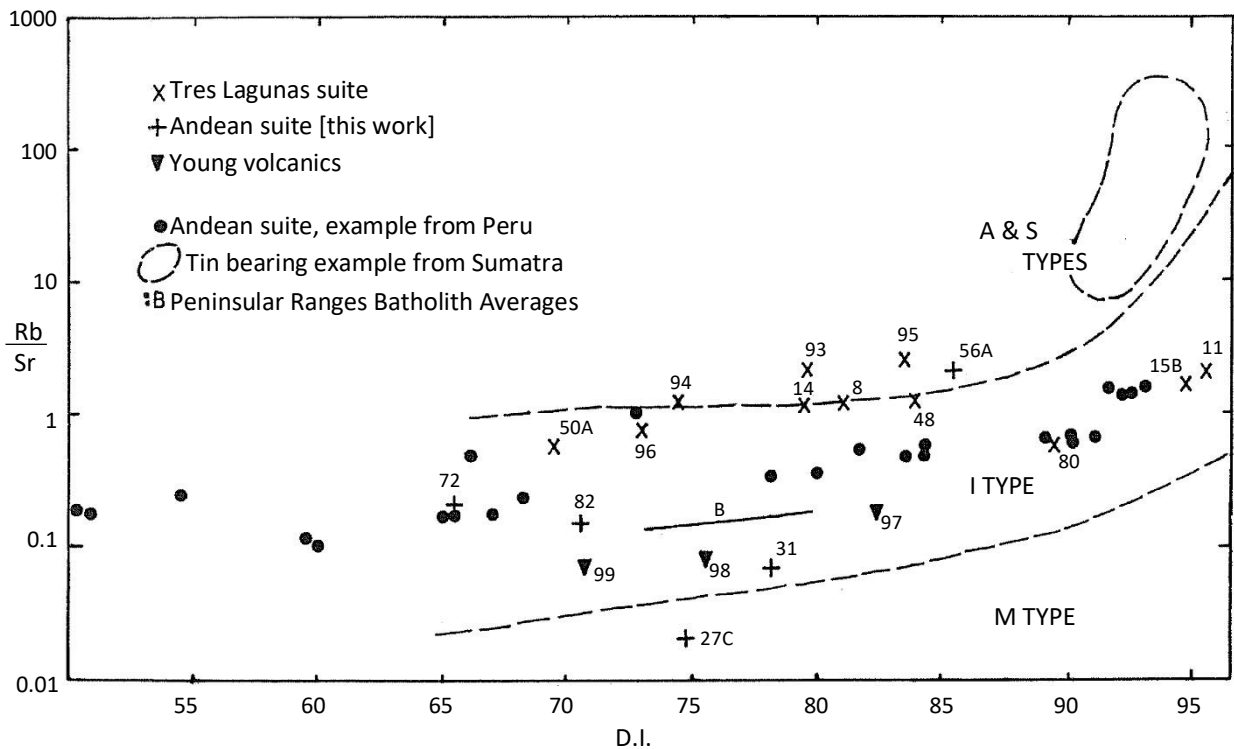
(a) Rb/Sr v D.I. (Differentiation Index) (Fig. 2.1)

This form of variation diagram has proved very useful to distinguish various suites of SE Asian granites. Rb/Sr essentially gives an indication of increasing crustal component and at intermediate compositions is virtually independent of the degree of differentiation. Rb/Sr however increases at more evolved (more highly differentiated) compositions in individual suites e.g. the Andean suite from Peru.

The two hatched lines divide the diagram into 3 fields - for A and S types, I and M (Mantle) types. Various examples are plotted and it can be seen that the Ecuadorean TLG suite straddles the I - S boundary, i.e. it is not a typical cordilleran suite but equally the analyses plotted do not indicate that it is a typical tin granite, most of which plot in the high Rb/Sr and highly differentiated part of the diagram, as, e.g. the Sumatran values.

The five 'I' type and three young volcanic analyses mostly plot within the 'I' type field.

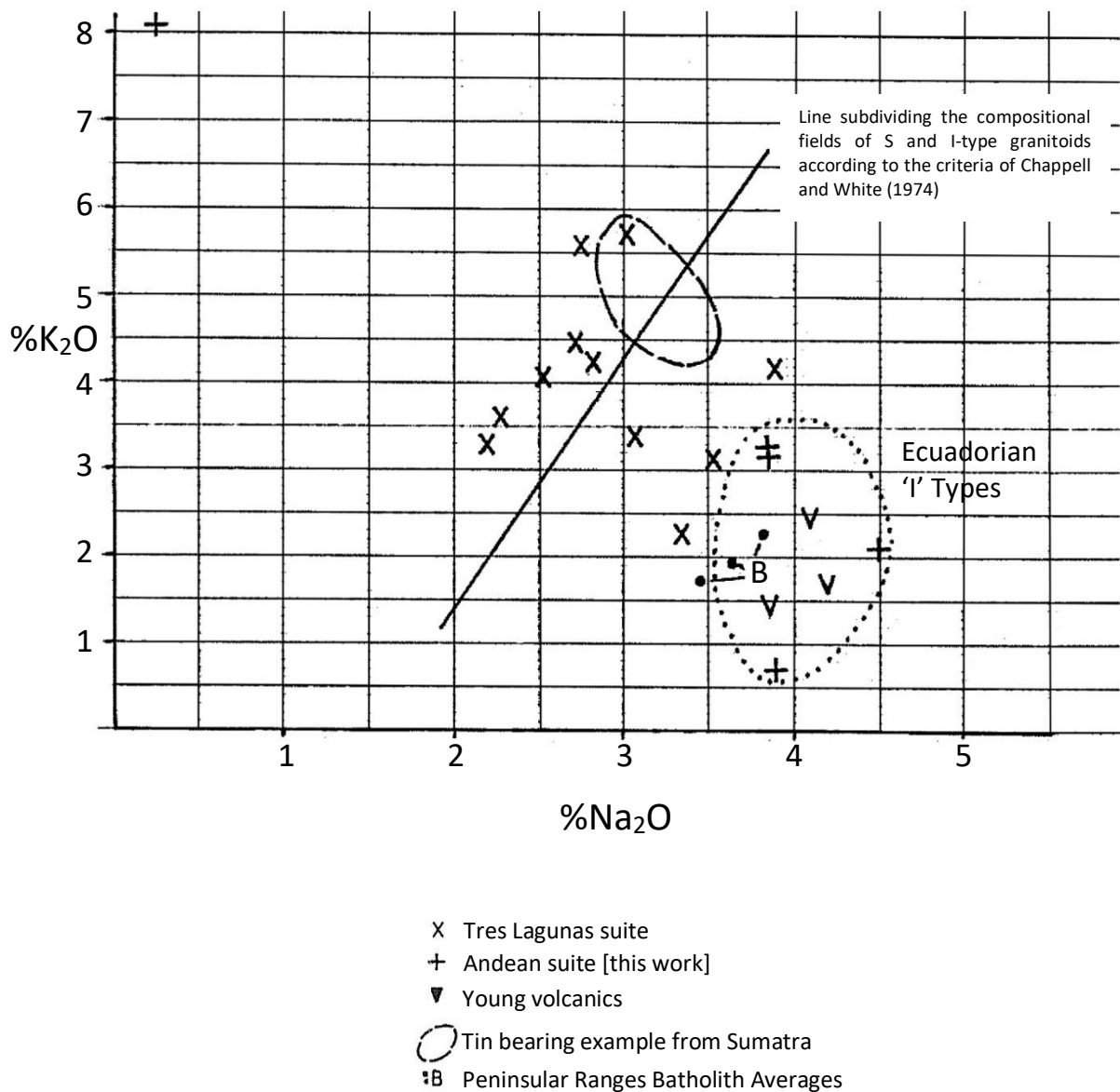
Figure 2.1. Diagram Rb/Sr vs D.I.



(b) K_2O vs Na_2O (Fig. 2.2)

This diagram derives from Chappell and White's early work. Both the Sumatran tin granite and the TLG data straddle the field boundary but are not overlapped by the Ecuadorean 'I' types, which occupy the same part of the plot as the average Peninsular Ranges values. This data spread implies that the TLG suite has an 'S' type affinity.

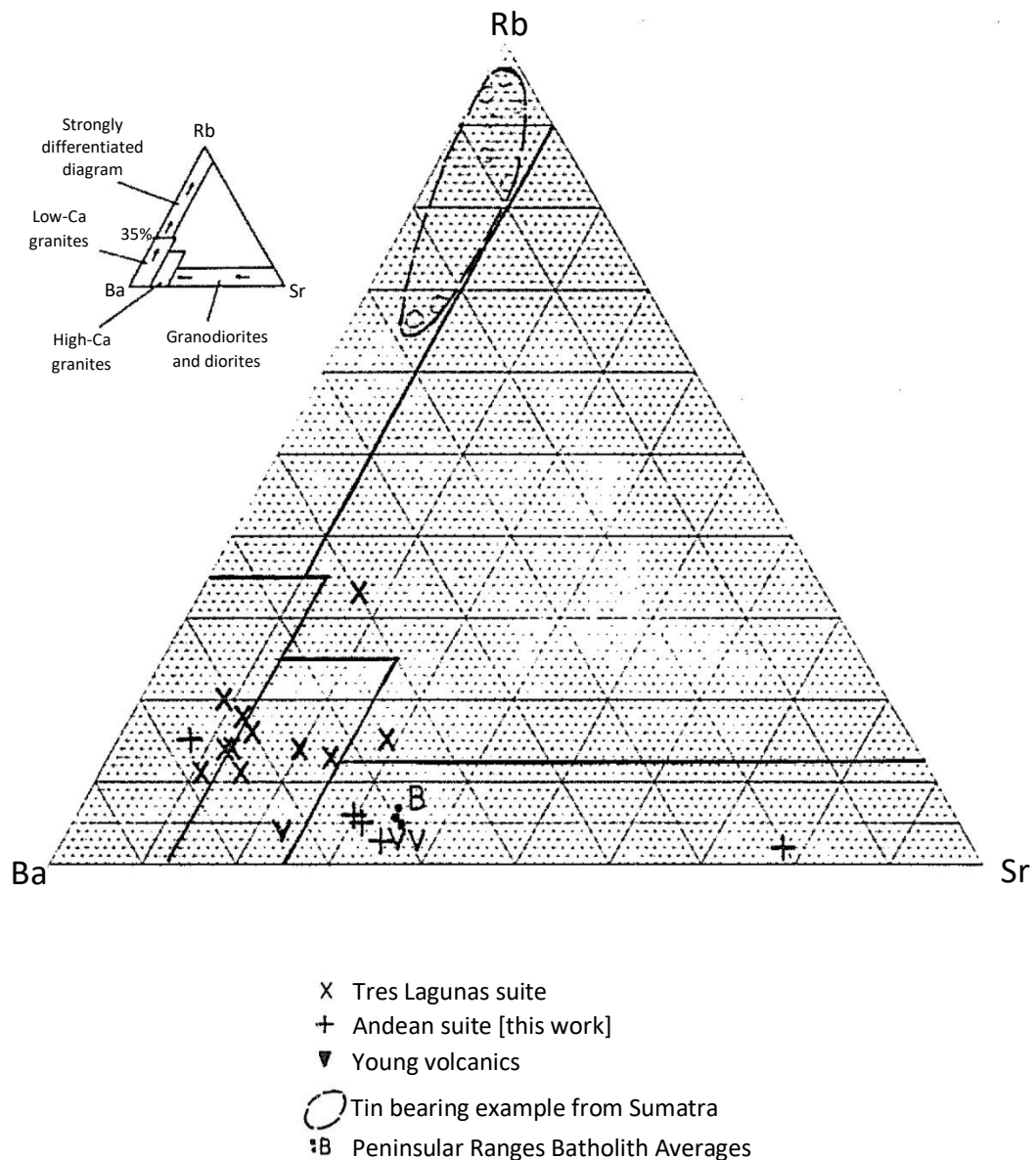
Figure 2.2 Diagram K_2O vs Na_2O



(c) Ba-Rb-Sr ternary diagram (Fig. 2.3)

The variation of these three elements plotted on a triangular diagram indicates that the TLG suite is extremely poorly differentiated by comparison with tin granites as exemplified by the field of the Sumatran suite. The Ecuadorean 'I' types together with average cordilleran compositions (B) plot in the field of granodiorites as predicted.

Figure 2.3 Ba-Rb-Sr ternary diagram

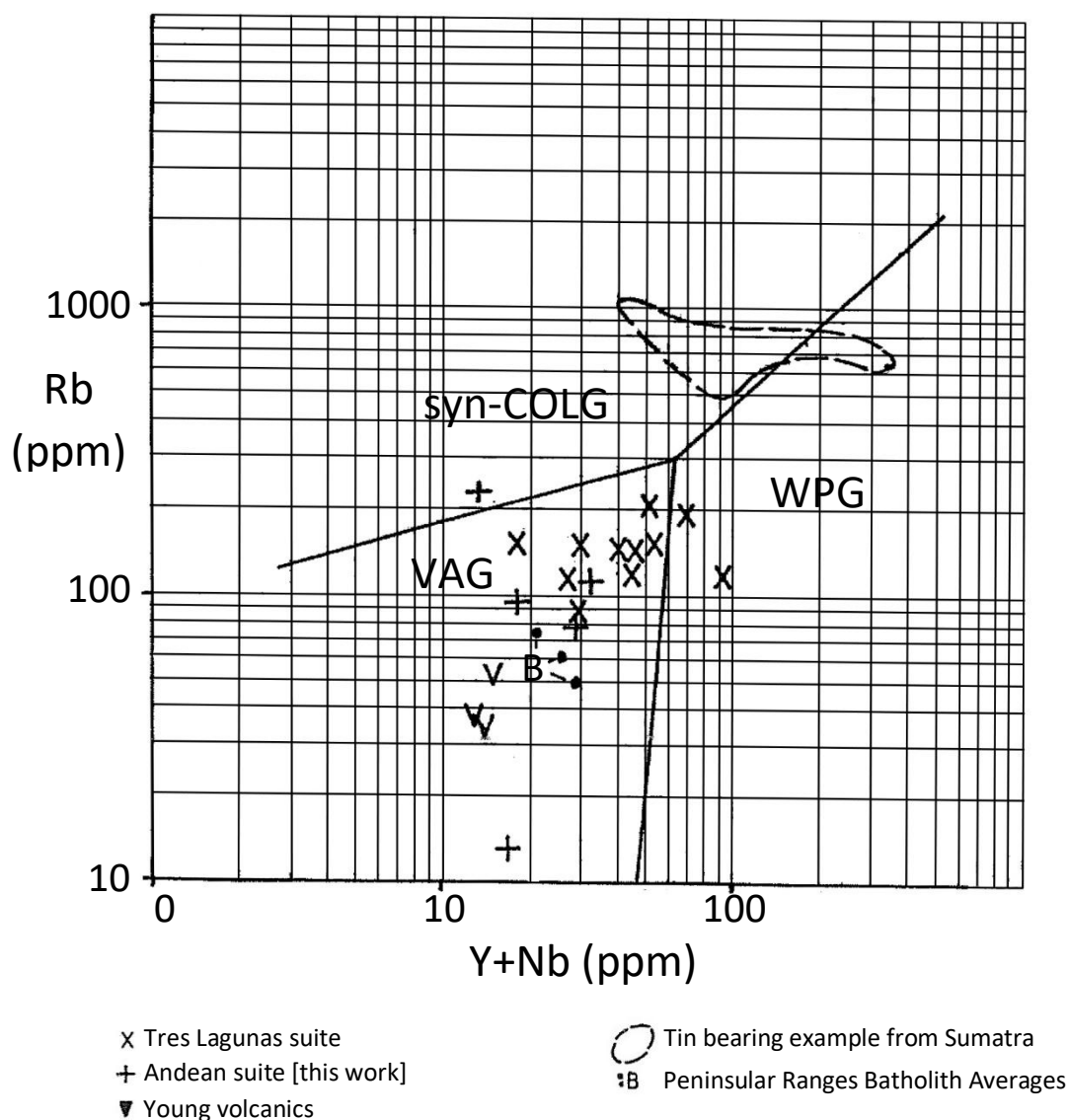


(d) Rb vs Y + Nb (Fig. 2.4)

This well used diagram proposed by Julian Pearce is frequently invoked to relate composition to environment. The TLG suite plots well below the boundary separating VAG (Volcanic Arc Granites or 'I' types) from syn-COLG (syn-collisional granites or 'S' types) with some overlap with the WPG (within plate granites or 'A' types). The Ecuadorean and cordilleran 'I' types plot centrally in the VAG field while the Sumatran tin granite data falls within the 'S' type field with some overlap into the 'A' type area.

On the evidence of this data spread the TLG suite is not a typical 'S' type, more like an 'I' type with slightly higher than average crustal component.

Figure 2.4 Diagram Rb vs Y + Nb



6.4 Conclusions

- (1) The geochemical data as depicted on the 4 diagrams allows two important deductions:
 - (a) The Tres Lagunas granite suite is not a typical cordilleran 'I' type.
 - (b) Equally, however, the geochemical parameters are not typical of highly differentiated 'S' type tin granites.
- (2) The Rb content and Rb/Sr ratio are higher than typical cordilleran compositions and this is taken to mean that there is a greater crustal component in the zone from which they are presumably derived.
- (3) Rb/Sr and Rb/Ba ratios are much lower than in the granites usually associated with tin even in the case of MC-15B & MC-11 which have extremely high Thornton & Tuttle differentiation indices (D1).
- (4) The low levels of tin assayed in various pegmatitic and vein samples (Tables 2-10), together with the almost total lack of cassiterite seen in pan samples correlate well with the geochemical data.
- (5) On present evidence the TLG suite should not be considered as localising a potential tin-tungsten province. Isolated concentrations of tin may be associated but only at Saraguro is there any evidence for such and that is not proved.
- (6) The geochemical data indicate, as mentioned, a probably greater than normal crustal component which would be expected in crustal-crustal collision generated granites.
- (7) Initial ratio data would be extremely useful to augment ideas on the genesis of this suite.

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7. REFERENCE 3

Mineralogical examination of a specimen of mineralised volcanic rock from Ecuador

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7.1 Introducción

This report is prepared in response to a request from Dr. M. Clarke of the BGS Overseas Division for examination of a single specimen 78E of mineralised volcanic rock from Ecuador. The objectives were to determine the petrology of the altered rock and of mineral veins it contained, and to determine the manner of occurrence of silver in it. The work was carried out under PA14BJ.

Specimen 78E is a single piece (ca. 8 cm wide) of “ore minerals hosted by a subvolcanic rock of porphyry type” from the Sub-Andean belt of Ecuador. The rock is said by Dr. Clarke to be associated with a mineralising episode and marked alteration of the country rock. It is representative of a sample which gave the following bulk-analytical results:

Au (g/t)	Ag (g/t)	Cu (%)	Pb (%)	Zn (%)	Cd (%)	Sb (%)	B (%)
0.35	37.0	0.03	0.08	2.75	0.024	<0.001	<0.01

The hand specimen shows pale grey, strongly altered porphyritic volcanic rock hosting a ca. 2 cm thick vein of massive brown sulphide. A network of hairline veinlets of brown sulphidic material is present in the host volcanic rock, which also contains fine-grained disseminated pyrite.

7.2 Work carried out

Two polished thin-sections were prepared to allow petrographic investigation of the rock and electron-probe micro-analysis (EPMA) of ore minerals. Section 78E/1 shows the vein and immediately adjacent wallrock; 78E/2 shows the general character of the wall rock. Optical examination in transmitted and reflected light was carried out using a Zeiss Universal Photomicroscope, and EPMA was carried on the Cambridge Instruments Microscan V microprobe at BGS Keyworth using LINK energy-dispersive X-ray analysis equipment. Areas on the section for EPMA were marked in opaque ink and photographed on 35 mm colour transparency film for reference.

The 15 micrographs are as follows:

- **PTS 78E/2**

- 1 area (g) ×20 reflected - sphalerite with galena and chalcopyrite inclusions
- 2 area (f) ×20 reflected - sphalerite with galena and pyrite inclusions
- 3 area (e) ×20 reflected - sphalerite with chalcopyrite and galena inclusions
- 4 area (d) ×20 reflected - pyrite free of inclusions
- 5 area (a) ×20 reflected - sphalerite (+ chalcopyrite) against galena
- 6 area (c) ×20 reflected - sphalerite with quartz, pyrite and galena inclusions

- **PTS 78E/1**

- 7 area (e) ×10 reflected - sphalerite with pyrite and galena inclusions.
- 8 area (d) ×10 transmitted - altered wallrock crossed by a vuggy fracture containing quartz, pyrite and Cu-Pb sulphate (see EPMA Table 4).
- 9 area (d) ×10 reflected - as in photo 8 but here in reflected light.
- 10 area (c) ×10 reflected - sphalerite with galena and other inclusions
- 11 area (b) ×10 reflected - sphalerite with galena and other inclusions
- 12 area (a) ×20 reflected - sphalerite with galena inclusions
- 13 near area (a) ×5 reflected - massive sphalerite with galena inclusions, passing into the central sphalerite + quartz + sericite "veinlet".
- 14 near area (a) ×5 transmitted - same field as in photo 13.
- 15 near area (a) ×5 transmitted - (crossed polars) - field as in photo 13.

7.3 Petrography

The sulphide vein consists of massive sphalerite enclosing a central, late-formed zone in which sphalerite is finely intergrown with quartz and sericite. Much of the sphalerite is pale brown in thin section, but a deep red variety occurs as marginal zones adjacent to the wallrock, margins adjacent to the central zone of the vein, intergrown with quartz etc. within the central zone, and zones developed about fractures crossing the massive areas of pale sphalerite. The pale variety is effectively free of mineral inclusions, but the dark variety is rich in minute inclusions of chalcopyrite, pyrite and galena.

The wallrock is abundantly plagiophyric dacitic porphyry. The feldspar phenocrysts have been altered to fine-grained mats of sericite which appear white in the hand specimen: the groundmass to finely intergrown quartz, sericite and pyrite. Potassium-feldspar may also be present in the groundmass, but this was not confirmed. Minor constituents include rutile and apatite. Within about 5 mm of the massive sphalerite vein the wallrock is altered to pale grey, more dominantly quartzose material.

The network of hairline veinlets comprises early quartz veinlets cut by later, more abundant quartz-sulphide veinlets. These latter contain pyrite and deep red sphalerite. This sphalerite contains minute inclusions of pyrite, chalcopyrite and galena. One veinlet very close to the margin of the main vein (see photo 8) is distinct in that it is vuggy, containing euhedral quartz prisms and crystals of pyrite partially enveloped in opaque material which under reflected light appears to have very low reflectivity and to be tarnished (EPMA data in Table 4 suggests that this is a Cu-Pb sulphate mineral).

It is evident that the specimen represents dacitic porphyry which has undergone phyllic hydrothermal alteration related to intense fracture-hosted mineralisation. Two stages of mineralisation can be recognised. The earlier comprises deposition of pale brown sphalerite vein(s) in fractures. The later comprises deposition of deep red sphalerite containing chalcopyrite, pyrite and galena inclusions. This took place in a network of hairline veinlets and, intergrown with quartz and sericite, in a central zone formed within the earlier vein of massive pale sphalerite. Deep red sphalerite, with its attendant mineral inclusions, also formed by replacement of earlier sphalerite at this stage.

7.4 Electron Microprobe Analysis (EMPA) results

Quantitative analyses were made of sphalerite and galena in several parts of both thin sections. Additional analyses confirmed the identities of pyrite and chalcopyrite, and determined the composition of sericitic white-mica formed by replacement of feldspar phenocrysts. Quantitative results are given in Tables 1 to 10, each of which refers to a specific area of the thin sections (e.g. 78E/1-(A) refers to area A on thin section 78E/1). Weight-% totals are generally acceptable, though in the case of galena high totals may result from infrequent re-calibration of the lead standard. For this reason, it is better to regard the calculated Ag-contents as approximately correct rather than normalise the galena analyses to 100 %.

In thin section 78E/1, areas A and B are sphalerite with galena and other inclusions at the margin of the central zone of the sphalerite vein, area C is at the external margin of the vein, D is the vuggy veinlet with possible Cu-Pb sulphate referred to above, and E is part of a sphalerite-bearing veinlet ca. 1 cm away from the margin of the main sphalerite vein. In thin section 78E/2, areas A, B and C contain mm-sized patches of sphalerite, galena and pyrite at the intersection of veinlets, D is host porphyry with pyrite grains, and the remaining areas E, F and G are in sphalerite-bearing veinlets.

The results show that silver occurs as a minor constituent of the galena (argentiferous galena with up to 3.8 % Ag recorded), and that galena inclusions in sphalerite in veinlets away from the main vein have appreciably lower silver-contents than those within the main veinlet.

The sphalerite which hosts the inclusions of argentiferous galena (etc.) is rich in iron and manganese (maximum concentrations measured: 11.74 % Fe and 3.76 % Mn), whereas the pale, inclusion-free variety of sphalerite is low in these elements (typically Fe ca. 2 % and Mn below detection limit of about 0.3 %). Cadmium reached 0.57 % in iron-rich sphalerite in area A of the main vein.

Five analyses of sericite confirmed its identity as a potassic white-mica.

7.5 Discussion

The manner of occurrence of silver indicates its introduction during formation of the iron-rich sphalerite in the later stage of mineralisation. No specifically silver-minerals were located, and the mineralisation has a mesothermal rather than epithermal character as seen in this specimen.

The variation in Ag-concentration in galena within the main vein and in veinlet in the host rock suggests that the main vein represents a specific concentration of silver above the average 37 g/t (i.e. ppm) level for the rock as a whole. No evidence of the manner of occurrence of the gold was obtained, though its presence as a minor constituent of one or more of the ore minerals is probable.

Neil Fortey
9th February 1989

APPENDIX 5

BRITISH GEOLOGICAL SURVEY

Mineralogy and Petrology Series

TECHNICAL REPORT WG/89/9R

Petrography of some granitic rocks and a suite of mainly volcanic altered rocks
from the Cordillera Real, Ecuador

by

J. Dangerfield

Geographic index

Ecuador, Cordillera Real

Subject index

Granite, volcanic rocks

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Bibliographic reference

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London, British Geological Survey 1989

Petrography of some Granitic Rocks and a suite of mainly volcanic altered rocks from the Cordillera Real, Ecuador

1. Introduction

Nine samples of granites and granodiorites and nine samples of altered mainly volcanic rocks were submitted by Dr. M. C. G. Clarke.

Individual descriptions of the granitic rocks are presented together with a table of modal analyses of selected specimens. There follows a short discussion of the granite types present.

The suite of altered rocks is described and individual rock-names ascribed where possible. The styles of alteration are briefly discussed.

2. Description of the granitic rocks

- **CR-MC-11**

A medium grained grey granite which has suffered some cataclastic deformation.

Quartz occurs as strained anhedral crystals and in finer grained interlocking mosaics. The feldspar is mainly orthoclase microperthite occurring as anhedral and subhedral. In several areas quartz and orthoclase form micrographic intergrowths. Less than one third of the feldspar is plagioclase in the albite range. All the crystals are at least partly sericitised but only a few show any alteration to zoisite. All the mica in the rock is muscovite and almost all of this mineral occurs in small elongate flakes. Two large plates of the mineral exhibit some brown staining and may well have replaced biotite.

Much of the original hypidiomorphic granular texture remains intact, but deformation has led to the development of a weak foliation defined by the mosaics of quartz and wavy discontinuous foliae of muscovite. Other cataclastic features seen adjacent to the micaceous foliae are fractured plagioclase crystals and distortions of the micrographic texture, and, associated with the foliae, elongate zones of quartz granulation. For most of their length, however, the foliae follow grain boundaries rather than transect the larger quartz and feldspar crystals.

As indicated above some of the muscovite is replacing biotite, and the remainder is confined to foliae associated with recrystallised quartz. It seems likely therefore that all the muscovite originated from within the granite, the micaceous foliae forming from the destruction of groundmass feldspar.

- **CR-MC-31**

This is a fine-grained granodiorite which has suffered the earliest stage of cataclastic deformation. It is a pale grey rock in which a degree of foliation can be seen in hand specimen.

Quartz occurs throughout the rock in anhedral interlocking crystals 0.2 mm to 0.6 mm in diameter, commonly aggregated into elongate mosaics, or as much finer granular aggregates associated with micaceous foliae.

The principal feldspar is subhedral zoned plagioclase in the oligoclase to andesine range. Crystal sizes range from 1 mm to 1.5 mm in length with a few as long as 3 mm. Almost all the plagioclase is very fresh. In only a few cases are the centre zones of crystals sericitised or kaolinised with rare development of epidote.

Brown or brownish green biotite predominates over muscovite. Biotite occurs as single flakes throughout the rock but much of it is aggregated into elongate patches or impersistent foliae where it is commonly replaced by muscovite, epidote and zoisite. A little apatite is present as inclusions in biotite and scattered in the groundmass of the rock. Garnet was the only other accessory mineral noted.

The texture of the rock is still essentially hypidiomorphic granular but with the development of a weak foliation. The foliae are wavy and generally follow grain boundaries. In places, trains and small elongate zones of granular quartz are associated with the micaceous foliae, and help to define the foliation.

- **CR-MC-50A**

The rock is a medium to fine-grained granite. An abrupt change in grain-size is visible in the hand specimen but not so obvious in thin section.

Quartz is anhedral and distributed evenly throughout the rock. Many of the larger crystals, which may reach 2 mm in size, are strained but much of the quartz is present in areas of interlocking crystals 0.2 mm to 0.8 mm in diameter.

Potassium feldspar is rare. The plagioclase is extensively altered but seems to be all composed of albite. Crystals are subhedral to anhedral and range widely in size from 0.6 mm to 2 mm. The alteration products of the plagioclase are sericite, needles of actinolite and zoisite. Sericite and actinolite are present in almost all crystals, although one or the other may predominate in some cases. About half of the altered plagioclase crystals contain some zoisite but in a few the mineral is more abundant and tends to occur in the centre of the crystal, associated with actinolite rather than sericite. These differences in alteration products may indicate that at least some of the plagioclase was originally more calcic than albite and was probably zoned.

Biotite is plentiful, brown, pleochroic and generally unaltered, but some crystals show a little replacement by zoisite, epidote or chlorite. In contrast a few biotite crystals have been extensively altered to chlorite and some separate aggregates of chlorite, zoisite and epidote may also have been formed from biotite.

Apatite was the only accessory mineral noted. It is commonly associated with or occurs as inclusions within biotite or aggregates of biotite.

Apart from a rare and slight bending of biotite cleavage and some strain in quartz the rock shows no sign of deformation. The hypidiomorphic granular texture of the rock is largely intact.

- **CR-MC-50C**

A medium-to coarse-grained granite which has suffered cataclastic deformation and subsequent veining by tourmaline. The hand specimen exhibits a crude and rather irregular foliation defined by impersistent biotite and feldspar bands and more regular quartz bands. Tourmaline veins cut this banding both obliquely and at right angles and therefore post-date the deformation. The thin section shows that few large (2.5 mm to 3 mm) crystals of quartz remain. Much of the mineral has recrystallised into an interlocking mosaic of much smaller crystals.

The feldspar is mainly plagioclase in the albite range. Much of the mineral is extensively altered but some crystals remain comparatively fresh. Alteration is confined to sericite although some fine-grained material may be composed of a clay mineral.

Little original biotite remains having been replaced by aggregates of new fine-grained biotite, opaque iron oxide, zoisite, muscovite and quartz.

A few subhedral garnets are present, several of them occurring together in a curved line.

A vein of fine-grained granular quartz-tourmaline cuts the rock. Associated with it are clusters of coarser tourmaline crystals but the mineral has not invaded the body of the rock and none occurs more than a few millimetres from the vein.

- **CR-MC-52A**

This is a quartz-muscovite-feldspar-rock with chlorite, tourmaline, opaque iron oxide and a little biotite. Apart from a few large quartz crystals, which show strain, all the quartz has recrystallised into an interlocking matrix during cataclastic deformation. The principal feldspar is plagioclase in the oligoclase range, and can be almost unaltered to extensively sericitised. It occurs as individual crystals and in clusters with potassium feldspar.

Muscovite is present in large plates, streaked or dusted with opaque iron oxide in which case it is probably replacing biotite. Secondly it occurs as aggregates of small crystals and may be intergrown with chlorite. In places these aggregates are very fine-grained and are probably largely replacements for feldspar. Thirdly muscovite is strewn throughout the quartz mosaic in single crystals or small clusters.

Biotite occurs as rare large plates and as small flakes associated with muscovite.

Most of the tourmaline is formed into two large aggregates but rare small crystals and clusters of small crystals are present elsewhere in the specimen. Opaque iron oxide is scattered throughout the rock in small grains but is particularly concentrated with the muscovite-chlorite aggregates.

The rock has a marked schistose texture; the original granitic texture having been virtually destroyed. The high proportion of muscovite, about 40 %, suggests that the rock may have been greisenized before cataclastic deformation. Because the tourmaline is unstrained and unaltered it was probably introduced after deformation took place.

- **CR-MC-72**

This is a medium grained hornblende-augite-granodiorite. Quartz is anhedral and mainly occurs interstitially. The principal feldspar is plagioclase which is present in zoned and twinned subhedral and lies in the andesine range. The majority of crystals are extensively altered to kaolinite and sericite, but in contrast a few crystals are only slightly affected. The potassium feldspar is subhedral orthoclase.

The main ferromagnesian mineral is a colourless to pale green pyroxene which is probably augite rather than diopside. Also present is pleochroic pale yellow green to yellow green hornblende, in places showing a little alteration to a carbonate which is probably siderite. Biotite occurs in ragged flakes which are altered, especially along their cleavage, to chlorite, epidote and muscovite.

Accessory minerals are apatite and opaque iron oxide. The latter is scattered throughout the rock but is particularly associated with and included within hornblende, pyroxene and biotite. Only a very little apatite is present and occurs as rare inclusions in biotite.

- **CR-MC-80**

This is a granite which has been slightly deformed cataclastically. The hand specimen shows two textures, a medium grained granite and a pegmatitic development. In thin section some granulation can be seen around the margins of the larger crystals and this is associated with wavy intermittent foliae of muscovite. Most of the larger quartz crystals show strain and the groundmass quartz has recrystallised into an interlocking mosaic.

In the pegmatitic development the potassium feldspar is orthoclase microperthite but elsewhere it is orthoclase. Plagioclase occurs as zoned and unzoned oligoclase. A few of the crystals are unaltered and the remainder only slightly sericitised.

Biotite occurs in deep brown strongly pleochroic plates and has inclusions with radioactive haloes. Most of the mineral is fresh, the small amount of alteration being to chlorite and muscovite. Biotite occurs throughout the groundmass and associated with the bulk of the muscovite in impersistent foliae which wrap around the larger crystals of quartz and feldspar.

Zircon and apatite are present as accessory minerals.

- **CR-MC-82**

This is a dark grey medium-grained hornblende-biotite-granodiorite. In thin section the rock is seen to be beautifully fresh and unaltered.

Quartz is anhedral and strained. Potassium feldspar is orthoclase.

Plagioclase is very fresh and unaltered occurring in euhedral to subhedral crystals. Many of these are compositionally zoned and range from middle andesine to labradorite.

Biotite occurs in fresh ragged brown anhedral, rarely green at the edges of crystals. Inclusions of apatite and opaque iron oxide are common and one biotite crystal shows a little marginal alteration to epidote. Hornblende is present in fresh euhedral and subhedral crystals, and is pleochroic from pale yellowish green to darker green. The mineral has inclusions of opaque iron oxide and apatite, and a few crystals are partly altered to chlorite.

Accessories include apatite, opaque iron oxide, sphene, zircon and epidote. Apatite occurs as inclusions in or associated with ferromagnesian minerals and also in the groundmass. Opaque iron oxide is present as inclusions within ferromagnesian minerals, associated with sphene and, more rarely, scattered in the felsic groundmass. Sphene is present in three small clusters. The texture of the rock is hypidiomorphic granular.

- **CR-MC-93**

A coarse-grained highly siliceous grey granite with an SiO₂ content, calculated from the modal analysis, of about 85 %.

Quartz is by far the most abundant mineral. It is present mainly in large plates which show strain but also in a few finer-grained mosaics which occupy interstitial regions of the rock.

Almost all the plagioclase is albite. The mineral is extensively altered to sericite and many areas of plagioclase show considerable development of zoisite. Additionally, needles of actinolite occur as a patchy replacement in some crystals.

The potassium feldspar, an orthoclase perthite, is, in contrast with the plagioclase very fresh.

Biotite is also mainly fresh showing a little alteration to muscovite along the cleavage and some marginal replacement by zoisite in a few cases. Muscovite occurs both as an alteration product of biotite and scattered throughout the groundmass.

Apatite and opaque iron oxide are present as inclusions within biotite. Garnet occurs as several clusters of small crystals almost all of which are associated with biotite. It is possible that these small areas represent digested xenoliths.

3. Modal analyses of the granitic rocks

Modal analyses were carried out on thin sections of seven specimens; 1000 or 2000 points being counted in each case as indicated. The results are as follows:

Sample No.	11	31	50A	72	80	82	93
Quartz	42.8	47.0	33.0	14.3	38.9	28.4	64.6
K-feldspar	43.6	1.8	45.6	9.0	38.5	3.0	5.7
Plagioclase	6.2	36.1		61.3	16.4	50.7	18.2
Muscovite	7.4	3.7	0.2	0.3	3.8	-	2.5
Biotite	tr	9.3	14.8	2.9	2.4	9.0	8.7
Hornblende	-	-	-	2.2	-	8.6	-
Pyroxene	-	-	-	6.4	-	-	-
Chlorite	-	-	2.7	-	tr	tr	-
Epidote	-	1.5	1.2	-	-	tr	-
Zoisite	-	0.5	2.4	-	-	-	0.1
Apatite	-	tr	0.1	tr	-	tr	tr
Garnet	-	0.1	-	-	-	-	0.2
Sphene	-	-	-	-	-	tr	tr
Opaque oxide	tr	-	tr	3.7	-	0.4	tr
TOTAL	100.0	100.0	100.0	100.1	100.0	100.1	100.0
Number of points	1000	1000	1000	2000	2000	2000	2000

tr. (trace) indicates that the mineral was seen in thin section but not counted.

4. Discussion of granite types

Judged on the mineralogical criteria set out in Chappell and White (1974), seven of the specimens (11, 31, 50A, 50C, 52A, 80 and 93) are classed as representing S-type granites for the following reasons.

- (1) Hornblende is not present in any of these specimens.
- (2) Biotite is fairly abundant in three specimens (31, 50A and 93) and has probably been replaced by muscovite in the others (11, 50C, 52A and 80).
- (3) Garnet is present in three specimens (31, 50C and 93).
- (4) Apatite occurs in the groundmass of 31 and 80, although it also occurs as inclusions in biotite in 31, 50A and 93.

Only two specimens (72 and 82) are designated as representing I-type granites. These have the following characteristics.

- (1) Hornblende is present in both.
- (2) Muscovite is very rare in one and absent in the other.

- (3) The biotite content is low in 72 and although fairly abundant in 82 this does not necessarily rule out that a rock is of I-type.
- (4) Apatite inclusions are common in hornblende and biotite in 82 and the very small amount present in 72 occurs also as inclusions in biotite.

5. Description of the altered rocks

• CR-MC-6A

In hand specimen this rock seems to be extensively kaolinised and is traversed by a network of blue-green tourmaline veins.

The thin section shows the rock to be a quartz-porphyry in which anhedral to subhedral phenocrysts and microphenocrysts of quartz are set in a fine-grained (0.04 mm) groundmass of quartz, kaolinised feldspar, sheaves of sericite flakes and scattered clusters of green tourmaline.

Tourmalinisation has spread out from the network of veins and, in addition to the scattered clusters referred to above, has invaded and partly replaced larger irregular patches of the groundmass. The mineral is pleochroic from almost colourless to mid-green, and much of it is finely granular but some larger crystals, about 0.3 mm in length, occur in radiating sheaves. The rock is a kaolinised and tourmalinised quartz-porphyry.

• CR-MC-18

A bright green rock, traversed by quartz veins, which now consists principally of epidote and a little quartz. However, there are a few clues to the original constitution of the rock, and these are mainly of a textural nature.

In many areas of the section swarms of epidotised sub-parallel laths can be seen. The laths range from 0.2 to 0.4 mm in length and may well be pseudomorphs after groundmass plagioclase. In the same areas ovoid patches occur which could have been amygdales. Obvious phenocrysts in the original rock have retained sharp crystal outlines and been replaced by coarser epidote than that which has pseudomorphed the groundmass. The groundmass epidote is charged with dusty opaque iron oxide whereas the phenocryst areas are relatively free and clear. In a few places traces of a cleavage parallel to the length of original crystals can be seen. Although the outlines of the phenocrysts are sharp it is difficult to say what any particular pseudomorph represents. It is probable that both feldspar and ferromagnesian minerals were present and if the groundmass consisted of plagioclase laths, amygdales and iron-rich material it seems likely that the rock was a basalt. The phenocrysts could then have been of plagioclase or both plagioclase and iron-free pyroxene, the iron-rich pyroxene being present in the groundmass.

Some areas of the rock do not contain the laths. It is possible that epidotisation destroyed the finer-grained texture in some areas or that these regions represent small xenoliths of a slightly coarser grained basic igneous rock. It is tentatively suggested that the specimen is an epidotised porphyritic amygdaloidal basalt.

- **CR-MC-19B**

This is a blue-grey fine-grained porphyritic rock, the feldspar phenocrysts reaching 7 mm in length. The thin section shows mainly unaltered phenocrysts of plagioclase and extensively altered phenocrysts and microphenocrysts of hornblende, with microphenocrysts of ilmenite, set in a cryptocrystalline felsitic groundmass.

The plagioclase phenocrysts are zoned and twinned and compositionally show a range from andesine just into labradorite. A few crystals are unaltered and, in many others, alteration is restricted to the development of carbonate around their margins and along cleavage traces. In a very few cases there is extensive alteration to carbonate, chlorite and kaolinite.

Euhedral hornblende pseudomorphs occur throughout the rock. All the crystals are rimmed with opaque iron oxide due to magmatic corrosion. The rims were originally of magnetite now partly altered to pyrite. The remaining parts of the hornblendes are now composed of chlorite and carbonate. Generally, chlorite predominates in the larger phenocrysts while carbonate occupies the microphenocrysts. Most of the chlorite is penninite and the carbonate is probably calcite.

Much of the groundmass cannot be resolved but it includes carbonate, opaque iron oxide and a little hematite and chlorite. The rock is now a chloritised and carbonated porphyritic hornblende-andesite.

- **CR-MC-19C**

In hand specimen this is a white saccharoidal rock, impregnated with pyrite, composed of subangular fragments. Thin section shows these to be ortho- and meta-quartzites and a quartz-porphyry. The rock has been partly silicified and mineralised, with pyrite, hematite, gypsum and an unidentified brown fibrous mineral.

Chalcedonic silica has filled irregular and elongate cavities between the quartzite fragments, and the other minerals, in part, occupy similar sites. Large pyrite crystals and minute hematite flakes are scattered throughout the rock. Gypsum and the fibrous mineral are commonly intergrown and in some cases are associated with pyrite. Gypsum also occurs in many places within the quartzite fragments.

The rock is either a breccia or pyroclastic rock which has been mineralised.

- **CR-MC-27C**

A medium to coarse-grained igneous rock, with approximately equal felsic and mafic areas, consisting essentially of plagioclase and hornblende.

The plagioclase is extensively altered to fibrous actinolite, zoisite and some sericite, the remaining discernable portions of crystals being andesine in composition. Alteration is complete in many cases, and in most other crystals only the margins of the crystals have escaped.

Hornblende occurs throughout the rock but principally in glomeroporphyritic aggregates. It is mainly of the brown or yellowish brown “basaltic” variety, but a pale green variety also occurs, the colour change commonly taking place within crystals. In places hornblende has been replaced by epidote and chloritoid. Although plagioclase and hornblende account for the bulk of the rock several other minerals are also present in significant amounts. Quartz forms about 5 per cent of the rock but occurs interstitially and is therefore probably secondary. Another mineral occupying several percent of the rock is chloritoid. It occurs in clusters of randomly oriented crystals and in elongate aggregates of sub-parallel bladed crystals. Much of this mineral occurs interstitially but, in some areas, seems clearly to be replacing both plagioclase and hornblende, and in these cases may be intergrown with zoisite or epidote.

Some of the hornblende crystals show a little replacement by a brown-stained carbonate, possibly siderite, and hematite or limonite.

The rock is an altered hornblende diorite.

- **CR-MC-29**

The hand specimen is a bright green fine-grained rock traversed by quartz veins. In one area the rock is also cut by chlorite veins, and in thin section chlorite can be seen intergrown with vein quartz and at the margin of quartz veining. Quartz veining has probably occurred in two generations. The earlier consists of large strained plates of the mineral with included fragments of “country rock”; the later of an interlocking mosaic of crystals occurring as patches and thin veins.

The rock appears to consist of an aggregate of coarser- and finer-grained fragments which are now composed essentially of epidote and quartz. Three types can be recognised:

- (1) A finer grained rock consisting of more than 90 % epidote with quartz confined to small patches.
- (2) A finer grained rock in which epidote and quartz are present in approximately equal proportions, but are unequally distributed, each mineral tending to form clusters and continuous patches. A little penninite is present and a very few elongate epidote crystals may be pseudomorphs after feldspars.
- (3) A coarser grained rock consisting of about 80 per cent epidote with quartz forming scattered aggregates. This fragment also contains a very little interstitial penninite. Both quartz and epidote have inclusions of small pale green needles which are probably of actinolite. Some of the epidote crystals are lath-shaped and may be pseudomorphs after plagioclase.

Because of the extensive epidotisation it seems likely that the fragments were all originally of fine-grained basic or intermediate igneous rocks. If the fragmentary nature of the rock is set aside, it could well be termed an epidosite.

- **CR-MC-46C**

This is a cataclastically deformed rock that has been epidotised and veined with quartz and calcite. A very little pyrite is also present in scattered crystals and aggregates. The carbonate veining postdates the quartz veining which in turn cuts through epidotised areas. Because the epidote is granular and not itself deformed, epidotisation followed cataclastic deformation of the original rock. The identification of this is difficult as only quartz remains but it was probably a medium-to coarse-grained acid igneous rock, although there is no real trace of any igneous texture

Penninite occurs in irregular patches and intergrown with some areas of epidote, and in a few places a little calcite has been deposited interstitially. A few late stage euhedral of quartz have occupied cavities, associated with penninite.

The rock is probably best called an epidosite.

- **CR-MC-60B**

This is a fine-grained grey porphyritic rock with pyrite and hematite deposited along joint surfaces. The thin section reveals plentiful phenocrysts and microphenocrysts of plagioclase and ferromagnesian minerals set in a cryptocrystalline felsitic groundmass. The rock is traversed by impersistent hematite veins.

Plagioclase is turbid and extensively altered to kaolinite and sericite. In some crystals twinning and compositional zoning can still be seen and demonstrate a range in composition which straddles the andesine-labradorite boundary.

The principal ferromagnesian mineral is an amphibole, determined on the occurrence of a few basal sections, now entirely chloritised, and containing blebs and strings of opaque iron oxide. Much of the mineral occurs as microphenocrysts.

Pyroxene is somewhat less altered than amphibole, but in many cases is partly replaced by iron oxides. It is colourless to very pale green and is probably diopside.

A few phenocrysts now replaced by wavy alternating bands of chlorite and opaque iron oxide may well have been biotite.

The original opaque mineral, scattered unevenly throughout the rock in microphenocrysts, is magnetite now partly pyritised. Much of the opaque oxide replacing ferromagnesian minerals is also pyrite but ilmenite altering to leucoxene is also present.

The rock is an altered pyroxene-hornblende-andesite.

- **CR-MC-74**

In hand specimen this is a white rock scattered with limonite in spots and along joints. It consists of phenocrysts of quartz and a few extensively altered feldspars and ragged micas set in a cryptocrystalline spherulitic groundmass.

The quartz phenocrysts are euhedral and unstrained but somewhat corroded and commonly contain inclusions of the groundmass material.

The small amount of phenocrystic plagioclase occurs as individual crystals or aggregates, in which parts of the outlines are still quite distinct but all other features have been destroyed. Alteration of the feldspar to kaolinite and a little sericite is complete. The distribution of feldspar is best seen in hand specimen. The mica was originally probably biotite because of its alteration to opaque iron oxide and the associated brown staining, but much of the latter seen in hand specimen is probably due to weathering.

The groundmass, consisting mainly of kaolinised feldspar, is characterised by spherulites and wavy elongate sub-parallel cracks, now filled with a brown iron oxide, which may well be flow lines. Dusty opaque iron oxide grains are common throughout the groundmass.

6. Discussion of alteration styles

Suggestions about the original rock-types have been made at the end of each of the general descriptions of the altered rocks. In three specimens epidotization is so extensive that it is impossible to be sure of the original rock-type but names have been given to the other samples with more confidence. With the exception of 27C and possibly 46C the rocks were probably all lavas.

The group of nine specimens contains no fewer than fourteen alteration or replacement minerals although not all make a major contribution to alteration styles and eight occur only once in the suite of rocks.

Epidotization - the principal alteration is due to kaolinisation, or chloritisation or combinations of these. Minor roles are played by tourmalinisation, sericitization and the development of carbonate. A summary of the principal alteration styles is as follows:

6A	Kaolinisation and tourmalinisation	of quartz-porphyry
18	Epidotization	of ? basalt
19B	Chloritisation and carbonitisation	of andesite
19C	[see below]	
27C	Saussuritization epidotization	of diorite
29	Epidotization and chloritization	of ¿?
46C	Epidotization and chloritization	of ¿?
60B	Epidotization and chloritization	of andesite
74	Kaolinisation	of quartz-porphyry

The alteration of 19C is different from that affecting all the other specimens. The combination of gypsum, pyrite, hematite and chalcedonic silica indicates modification by fumarolic activity, in this case the filling of voids in a breccia or tuff.

The occurrence of chloritoid as a replacement mineral in specimen 27C is interesting. The mineral is normally found in low to medium grade schists which have a relatively high content of alumina, but has also been reported from contact aureoles and hydrothermally altered rocks. (Halferdahl, 1961). Of particular interest are associations with the gold deposits of Kalgoorlie (Simpson and Gibson, 1912) and the Rand (Read, 1951).

Propylitization, strictly speaking, only applies to the alteration of andesites and dacites where the original feldspar and ferromagnesian minerals have been replaced, principally by epidote, chlorite and calcite, due to the action of hydrous solutions rich in carbon dioxide. In this suite of rocks, the term can therefore only be used to describe the alteration suffered by specimen 19B although it might also be applied to 18, 19 and 46C if these specimens were thought to have originally been andesites. In most instances propylitization is ascribed to deuteric solutions but in others it appears to result from the introduction of similar solutions from extraneous sources into already solid andesites. Propylitized rocks are found close to ore bodies but the relationship may not be genetic (Williams, Turner and Gilbert, 1958, p.96).

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APPENDIX 6

BRITISH GEOLOGICAL SURVEY

Mineralogy and Petrology Series

TECHNICAL REPORT WG/89/1R

Mineralogical examination and analysis of samples from Ecuador

by

B. Beddoe-Stephens

Geographical index
Ecuador, Cordillera Real

Subject index
Gold, sulphides, Sn, W

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Edinburgh, British Geological Survey 1989

Mineralogical examination and analysis of samples from Ecuador

Mineralogy and Petrology – Informe No. WG/89/1R

B. Beddoe Stephens

January 1989

1. Introduction

This report comprises an examination of a suite of samples collected by Dr. M. C. G. Clarke of the Overseas Directorate as part of the Anglo-Ecuadorian Cordillera Real Project aimed at identifying targets of potential economic mineralisation. The samples consist of about 60 panned concentrates and 19 rock/ore specimens. The former were subject to heavy liquid and magnetic separation in order to concentrate the non-magnetic heavy fraction which was then optically examined, particularly for the presence of gold. This fraction was also subject to 'tinning' and examination under UV radiation to test for the presence of cassiterite and scheelite, respectively. Golds were handpicked and mounted on glass slides and polished for electron probe analysis. Polished thin sections were prepared from all the rock/ore samples allowing reflected and transmitted optical microscopy and probe analysis to be carried out.

2. Description of rock/ore samples

The rock samples examined come from four broad areas geographically. All sample numbers are prefixed by CRMC (Cordillera Real Martin Clarke). A summary of the ore mineral assemblages is shown in Table 1.

2.1 Peggy Mine area

- **#7A**

This rock is composed essentially of quartz and tourmaline. There are some interstitial carbonate and patchy fine white mica. The quartz forms a mosaic of variable grain size and shows evidence of more than one episode of crystallisation. Blue-green tourmaline occurs as radially developed columnar or acicular aggregates. Several elongate crystals of opaque wolframite are noted, the electron-probe indicating that it is 60-70% ferberite. Sulphides are common and comprise arsenopyrite, chalcopyrite and pyrite-marcasite intergrowth. Rimming these sulphides or developed along grain boundaries is occasional bismuthinite which almost invariably includes irregular blebs of native bismuth (Figs. 1 and 2). The bismuthinite locally contains significant Sb, possibly as finely intergrown stibnite. Pyrrhotite is also present, usually as inclusions in arsenopyrite. Wolframite predates sulphide deposition, has irregular crystal margins and is cut by secondary quartz veinlets. Both wolframite and sulphide, however, show penetration by and inclusion of tourmaline prisms. Carbonate is late in the crystallisation sequence, exhibiting open space growth bands and interstitial habit between quartz and sulphide.

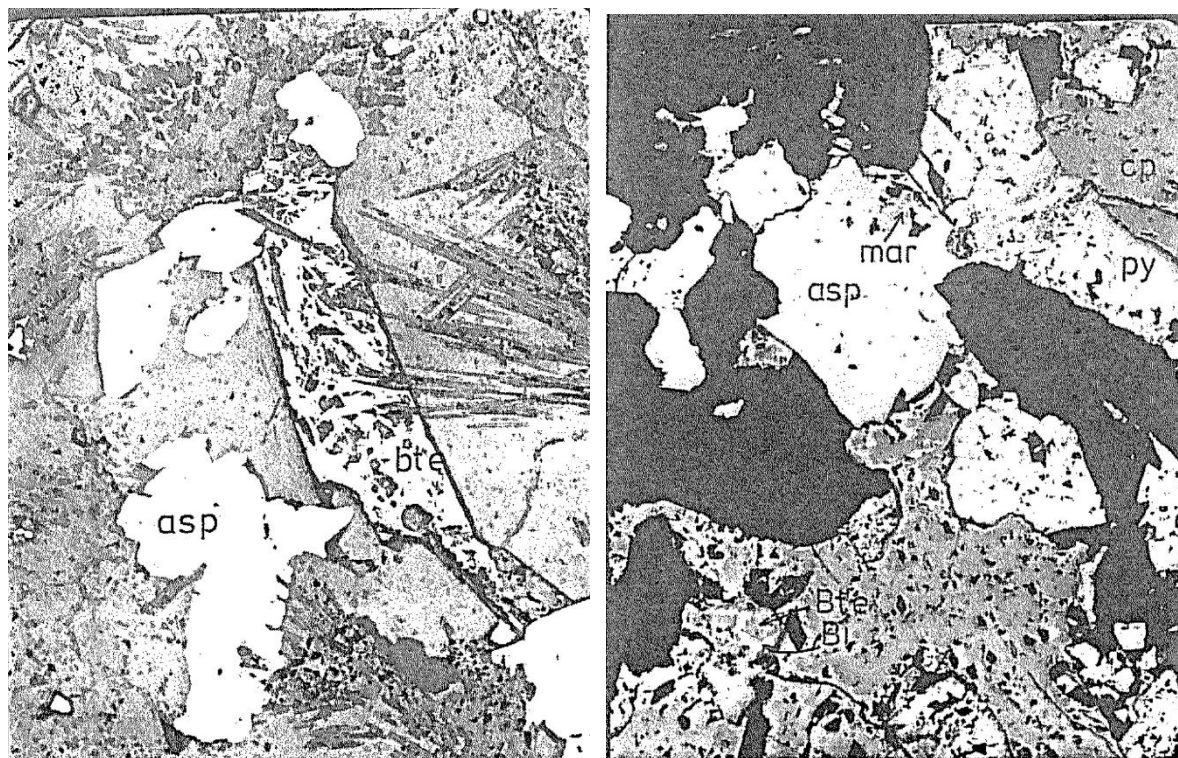


Figure 1. Quartz-tourmaline rock 7A contains arsenopyrite, pyrite-marcasite intergrowth and chalcopyrite. Late bismuthinite contains irregular blebs of native Bi.

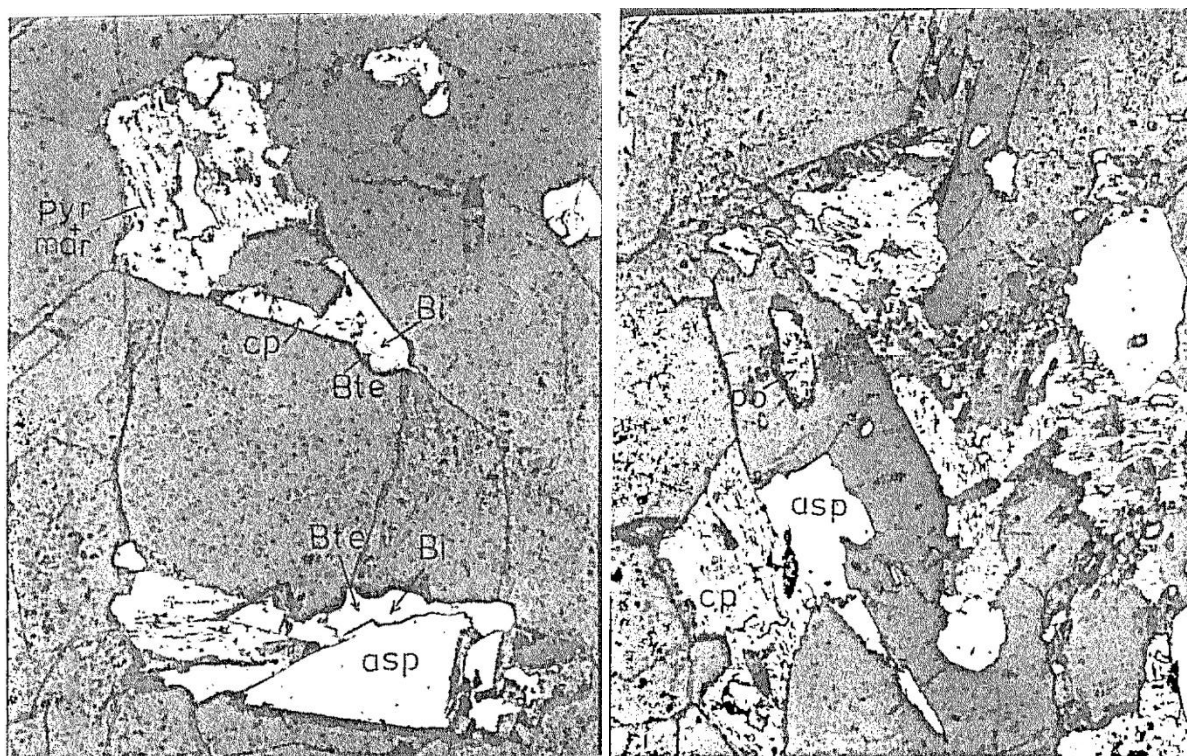


Figure 2. Sample 7A showing late bismuthinite-native Bi. Also pyrrhotite.

- #7C

Quartz is the main gangue mineral in this sample, forming an irregular mosaic, though white mica/sericite laminae are abundant giving a schistose fabric. Penetrative weathering of the rock has altered some mica to ferruginous clay. Pyrite-marcasite intergrowth, sometimes as a fine spongy aggregate, galena and sphalerite are the main ore phases with pyrrhotite as inclusions in pyrite. Stannite ($\text{Cu}_2\text{FeSnS}_4$) was observed in this section as a blocky crystal penetrating galena and as an irregular veinlet in sphalerite (Fig. 3). Postdating sulphide deposition is some locally well-crystallised carbonate which the probe shows to be siderite. A trace of chalcopyrite was also observed.

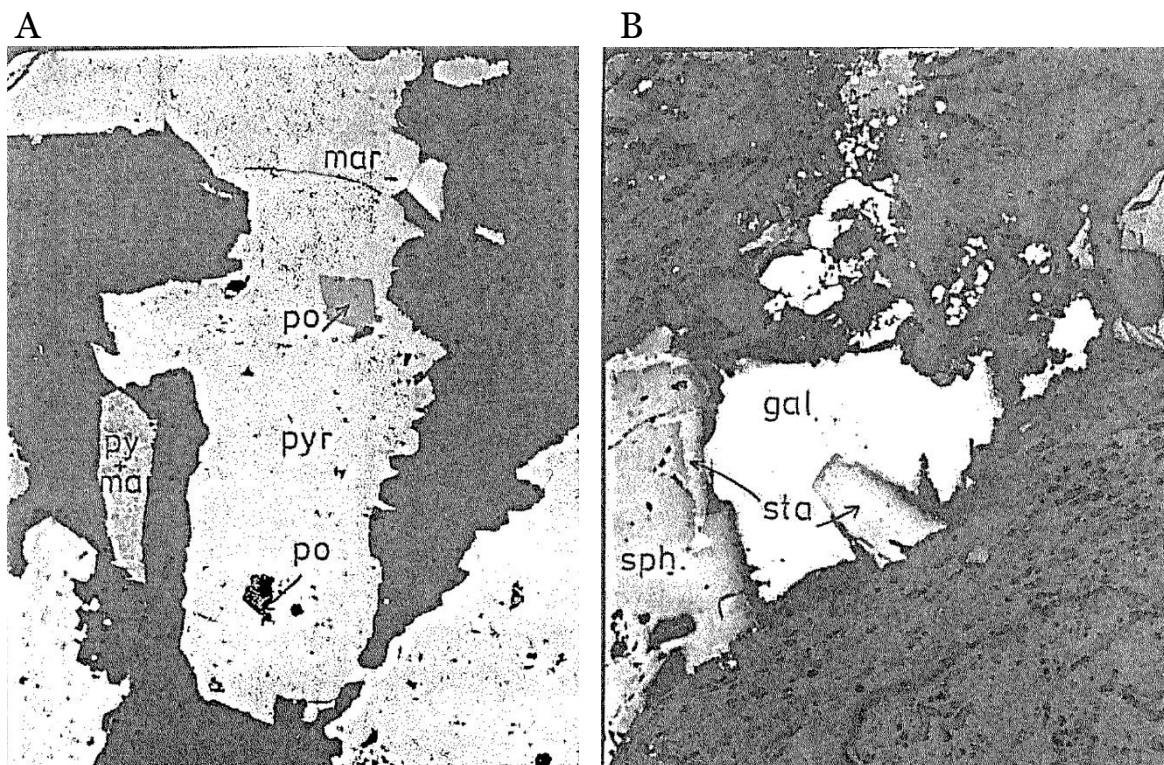


Figure 3. Sample 7C. A: Pyrrhotite inclusions in pyrite. Marcasite also intergrown with pyrite - locally as sponge-like crystal aggregates. B: Galena and sphalerite with stannite.

- #7D

This is a quartz-tourmaline rock similar to 7A, quartz occurring as a granular mosaic of variable grain size and partly interstitial green-blue-yellow tourmaline forming acicular/columnar radial aggregates. The probe indicates the tourmaline is Fe-rich i.e. schorl. Similarly to 7A, arsenopyrite, chalcopyrite and pyrite-marcasite intergrowth are the main sulphides with late bismuthinite and native Bi. Pyrrhotite inclusions occur in arsenopyrite. Figure 4 illustrates textures in this rock. Minor interstitial carbonate is noted.

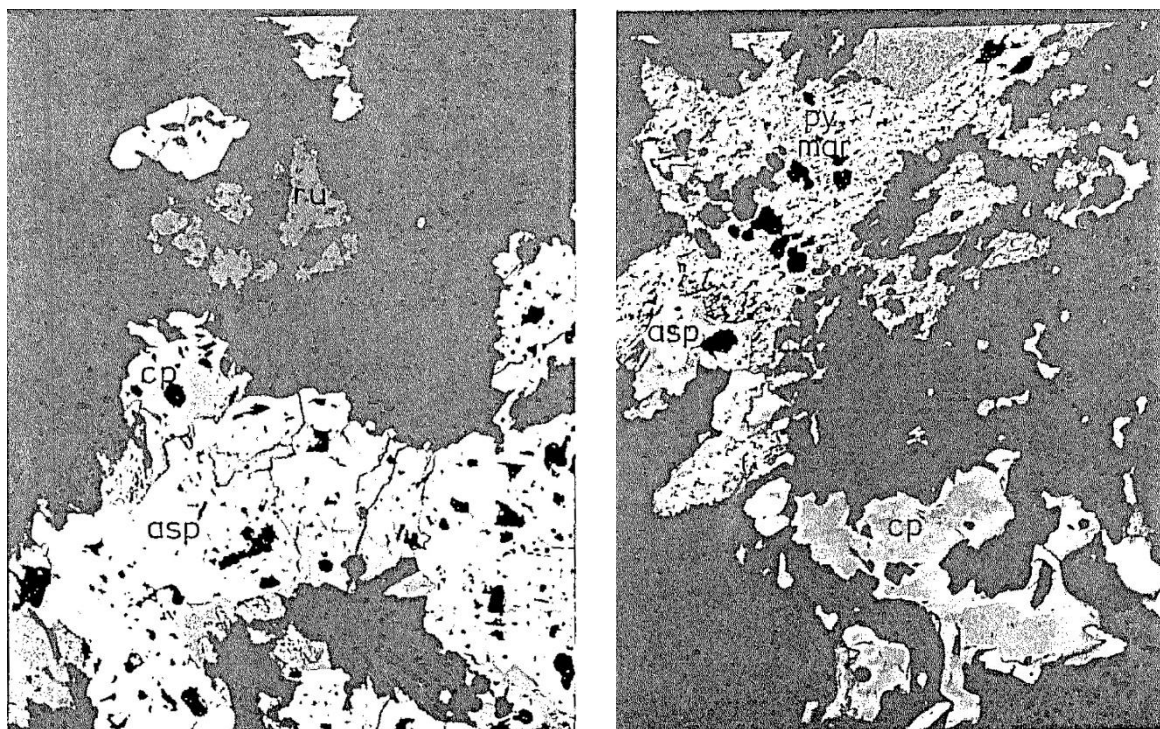


Figure 4. Sulphide assemblage in sample 7D comprised of arsenopyrite, chalcopyrite, pyrite-marcasite intergrowth and late bismuthinite with native Bi blebs. Rutile also evident.

- **#9**

This rock is also composed of quartz and tourmaline (schorl) but exhibits no sulphide development. Quartz development was complex with some crystals retaining evidence of strain and radial crystallisation habit with later annealing forming an unstrained granular mosaic. Tourmaline is concentrated into sub-parallel bands. However, an unusual phase was noted, appearing high relief in thin section and forming interstitial pale green-yellow radial, fibrous crystals. The probe indicates only the presence of Fe and As suggesting it is a mineral related to karibibite ($\text{Fe}_2\text{As}_4\text{O}_9$) or angelellite ($\text{Fe}_4\text{As}_2\text{O}_{11}$), or a hydrated phase such as symplectite. It requires further probe work and XRD to characterise this phase properly.

- **#22C**

Rounded to subhedral quartz phenocrysts up to several mms in diameter characterise this rock. They are set in a fine grained quartzose matrix with abundant fine mica. Tourmaline occurs as prismatic clots often associated with laths or rosettes of fine white mica. In part these appear to be pseudomorphic after feldspar phenocrysts. Tourmaline also occurs in thin veinlets with quartz which have an Fe-stained selvedge due to the presence of disseminated limonitic material and minor hematite.

Tourmaline, indicative of B-rich metasomatic fluids, is characteristic of this area. Also, the association of minerals containing Sn and W, and As, Bi sulphides is typical of mineralisation associated with evolved (?S-type) epizonal or mesothermal granites.

2.2 Ayllón area

• #25

Quartz as a mosaic of variable grain size forms the gangue to this rich ore sample. Fine white mica is associated with bands of finer quartz. Massive pyrite forms irregular bands and common angular arsenopyrite clusters border these. Galena and sphalerite also occur, the latter with inclusions of chalcopyrite. Boulangerite ($\text{Pb}_5\text{Sb}_4\text{S}_{11}$) postdates these main sulphide phases, replacing galena along grain margins in places (Fig. 6). Native gold is conspicuous in this sample, often associated with boulangerite with which it co-crystallises or just postdates (Fig. 5), but also as specks between other sulphides or on fractures. A related phase, bournonite (PbSbCuS_3), was noted as late veinlets; in Figure 6 cutting arsenopyrite and sphalerite.

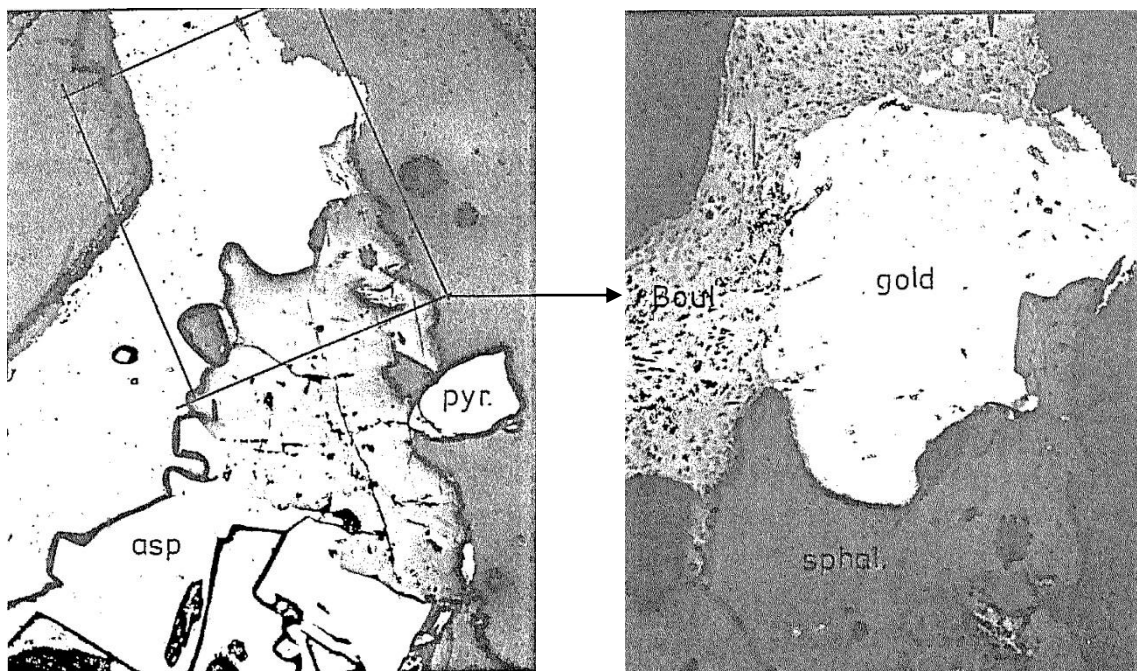
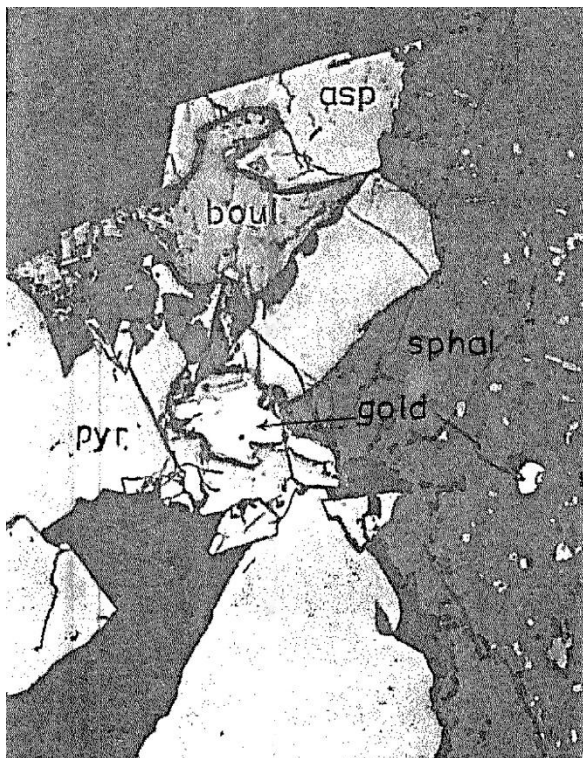
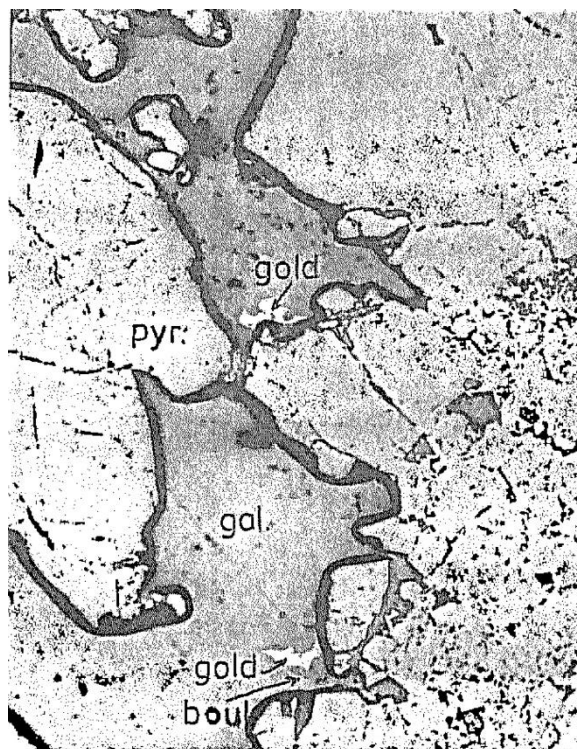


Figure 5. Large gold grain (400 μm) in sample 25 associated with sphalerite and boulangerite. Arsenopyrite and sphalerite probably co-crystallized and are postdated by boulangerite. The gold contains boulangerite inclusions which together with the irregular margin between them suggests gold was the later phase. Chalcopyrite inclusions occur in sphalerite.

A



B



C

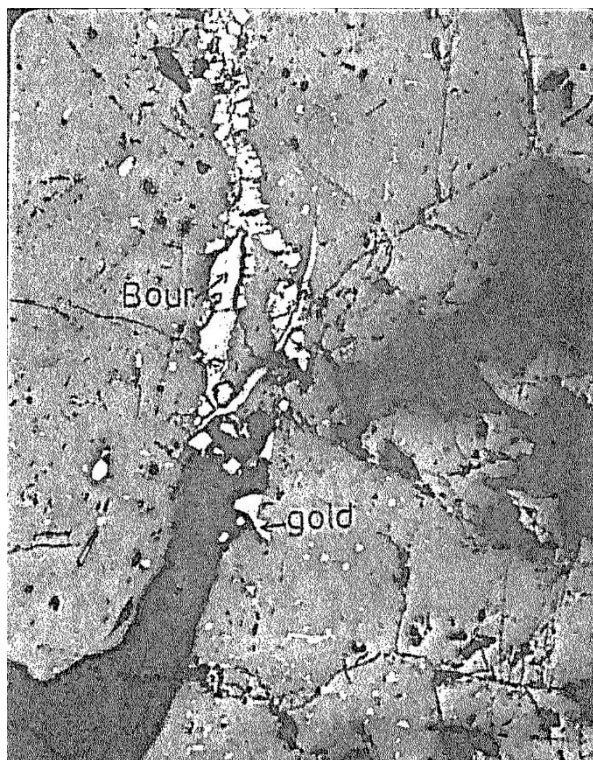


Figure 6. Sample 25.

A: Gold as blebs in sphalerite and associated with boulangerite. Pyrite and arsenopyrite also present.

B: Galena in pyrite is marginally replaced by boulangerite with which are associated gold blebs.

C: Gold in sphalerite. Late bournonite veinlets cut earlier pyrite plus arsenopyrite stringer in sphalerite.

- **#27A**

This sample is also composed of a gangue of granular quartz with finer bands containing occasional pockets of white mica. The only sulphides identified however are common arsenopyrite and subsidiary galena. Native gold was identified in section as shown in Figure 7. It appears to postdate galena and arsenopyrite.

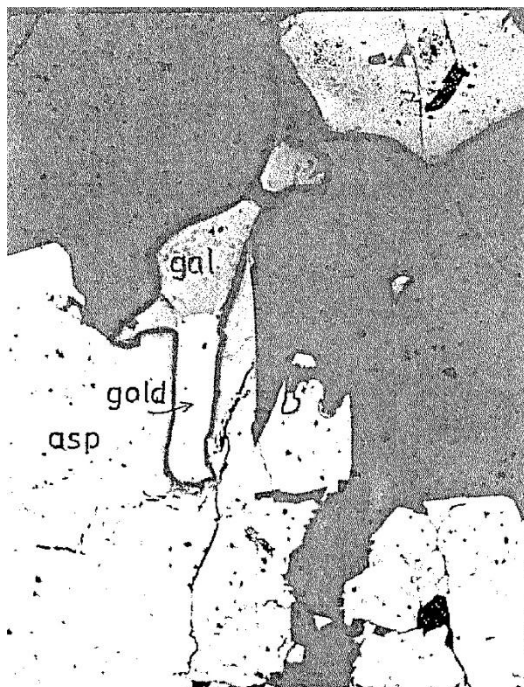


Figure 7. Gold grain (300×100 μm) in sample 27A associated with arsenopyrite and galena.

- **#30**

This is a sample of massive ore composed almost entirely of an equigranular pyrite with subsidiary subhedral magnetite. The magnetite exhibits partial alteration to hematite along crystal margins and octahedral partings. Chalcopyrite occurs as rounded inclusions in pyrite and also along fractures. Minor radially crystallised quartz and Fe-hydroxides occur interstitial to pyrite.

The two quartz vein samples represent polymetallic (As-Au-Sb-Pb-Zn) hydrothermal vein deposits. The similarity of native gold composition (see below) in these samples suggest they are related. This also appears to be a relatively Cu-poor association and the lack of discrete Ag minerals together with a bulk Au/Ag ratio >1 suggests a mesothermal rather than epithermal origin.

The massive pyrite-magnetite ore (#30) is clearly different and a possible origin would be as a metasomatic rock formed close to the contact of a granitoid body.

2.3 Zumba area

- **#38**

A quartzose rock showing evidence of repeated fracture and silicification. Some feldspar is evident but is altered to fine mica or clay and possibly fine saussurite. There are also patches of fine-grained green chlorite or montmorillonite. Disseminated pyrite crystals occur as well as red-brown oxidation products including goethite.

- **#43A**

This is a strongly 'propylitized' sample. The local presence of relict feldspar and pseudomorphed pyroxene phenocrysts indicate it was originally a porphyritic andesitic rock. It has substantially altered to an assemblage of actinolite, prehnite, epidote and quartz, plus minor chlorite. Pyrite occurs as irregular disseminated crystals together with a trace of chalcopyrite.

- **#43B**

A similar rock to 43A, showing a heterogeneous texture and with an alteration assemblage consisting of prehnite-epidote-actinolite-quartz. Pumpellyite is also tentatively identified in this rock. There are common equant, rounded pyrites and minor chalcopyrite. Covellite rims chalcopyrite in places.

- **#45**

This rock consists primarily of coarse, strained quartz and epidote, the latter as distinctive blocky clusters of zoned yellow/apple green crystals, occasionally presenting good crystal faces against quartz. The sample contains some massive magnetite which shows numerous fine hematite lamellae. Occasional interstitial clots of chlorite are noted. Sparse, very small grains of pyrite occur in the magnetite.

Samples 43 and 45 are possibly related to (?retrogressive) skarn due to the presence of Ca-Al silicates and massive magnetite. However, they are poorly mineralised.

2.4 Zamora area

- **#64C**

This rock consists predominantly of grossular garnet which exhibits characteristic non-isotropic optical behaviour and which forms a granular mosaic texture of variable grain size. Grossular shows distinct zoning and crystal face development adjacent to interstitial or vein quartz and calcite (Fig. 8). Visible gold grains ~ 1 mm across occur in hand specimen and a small gold crystal was revealed in the polished section. As Figure 8 shows, it has crystallised interstitially to garnet. Sparsely disseminated tiny pyrite euhedral occur in this rock plus a trace of chalcopyrite.

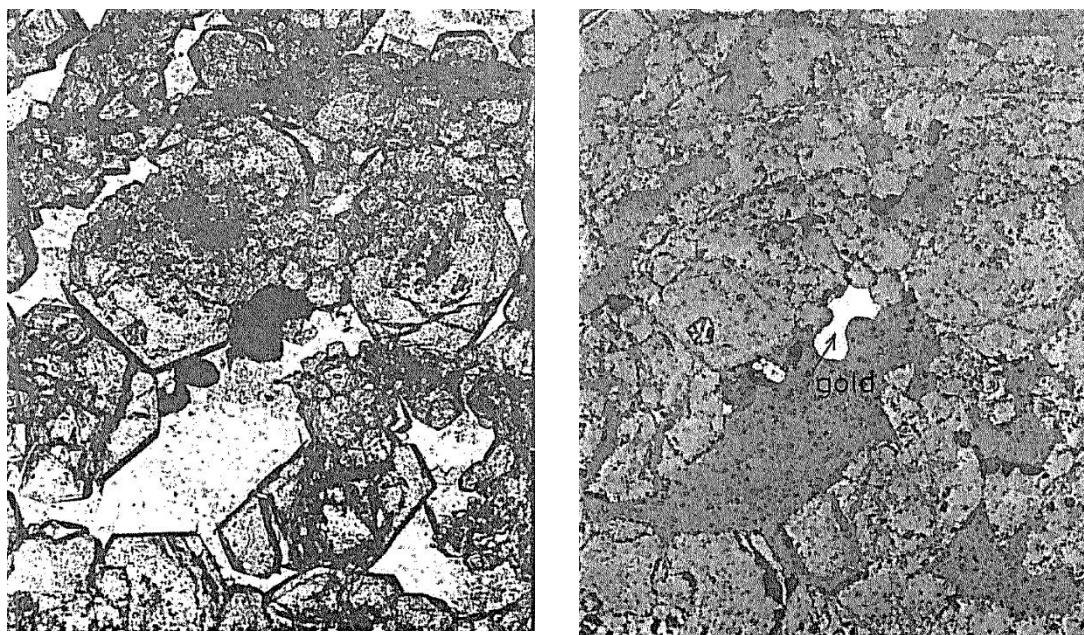


Figure 8. Garnet skarn 64C composed of euhedral mosaic of grossular-andradite with interstitial quartz and carbonate. Small lobate gold crystal postdates garnet.

- **#64E**

An interesting rock in that it is crystal-rich andesitic tuff partly made over to grossular skarn. Calcite, chlorite and traces of hematite occur interstitially to grossular. Angular to subhedral feldspar clasts in the andesitic protolith domain of this rock are rather cloudy. In this domain, fine patches and stringers of calcite act as nuclei to garnet growth. Transformation to virtually 100% grossular skarn occurs spatially over a few millimetres. Rare specks of pyrite are disseminated throughout.

- **#65B**

This is also a skarn which shows two distinct domains. One consists of abundant zoned yellow grossular-andradite with interstitial quartz, turbid feldspar and calcite; the other consists of numerous small clinopyroxene euhedral poikilitically set in a matrix of quartz and brown turbid (?K-)feldspar. Feldspar also occurs in veinlets postdating garnet growth and sometimes occur as alternate concentric growth bands with quartz. In hand specimen these veinlets are distinctly pink. There is only sparsely disseminated interstitial pyrite.

- **#69**

A breccia consisting mainly of clasts of plagioclase-phyric andesite. Feldspars are cloudy and exhibit patchy alteration to chlorite, epidote and ?pumpellyite. Prehnite also occurs in this rock. A few crystals of grossular indicate incipient skarn formation as does the presence of splays of elongate clinopyroxene. Some actinolitic aggregates may be pseudomorphic after primary hornblende or pyroxene. Minor chlorite occurs in veinlets and there are patches of carbonate. Pyrite is sparsely disseminated and only a trace of chalcopyrite was observed.

A description of a related skarn from Nambija, from which the above four samples originate, was given in a previous report (Beddoe-Stephens, 1987). In that sample (JACR#19) gold was identified and related to quartz-calcite-K feldspar deposition interstitially developed with respect to grandite garnet ($\text{Ad}_{70-45}\text{Gr}_{29-52}$).

- **#56A**

This is a quartz-feldspar porphyry. Rounded quartz phenocrysts are up to 4 mm in diameter. Rounded equant feldspar phenocrysts are more common than quartz but of roughly equal size. Most show simple Carlsbad twinning but a curious recrystallisation texture although they are fringed and partly replaced by white mica. Euhedral biotites show replacement by white mica and clay minerals. The matrix consists of granular cloudy feldspar, quartz and mica. Disseminated pyrites occur in the rock matrix, but pyrite plus sphalerite occur in a thin (1 mm) veinlet. Covellite also forms in the veinlet as a fringe on, or as replacement of sphalerite - only a trace of chalcopryite was noted.

- **#78B**

This sample is a vein breccia, the host rock being a feldspar-phyric andesite or dacite. It is silicified and argillised - feldspar phenocrysts being replaced by illitic clay minerals. Vein and clast interstice infill consists of comb-like quartz and sphalerite (translucent yellow-orange in thin section). Sphalerite contains irregular veinlets and inclusions of argentiferous galena, pyrite, pyrrhotite and chalcopryite (Fig. 9). Cubes of pyrite are disseminated through the host rock.

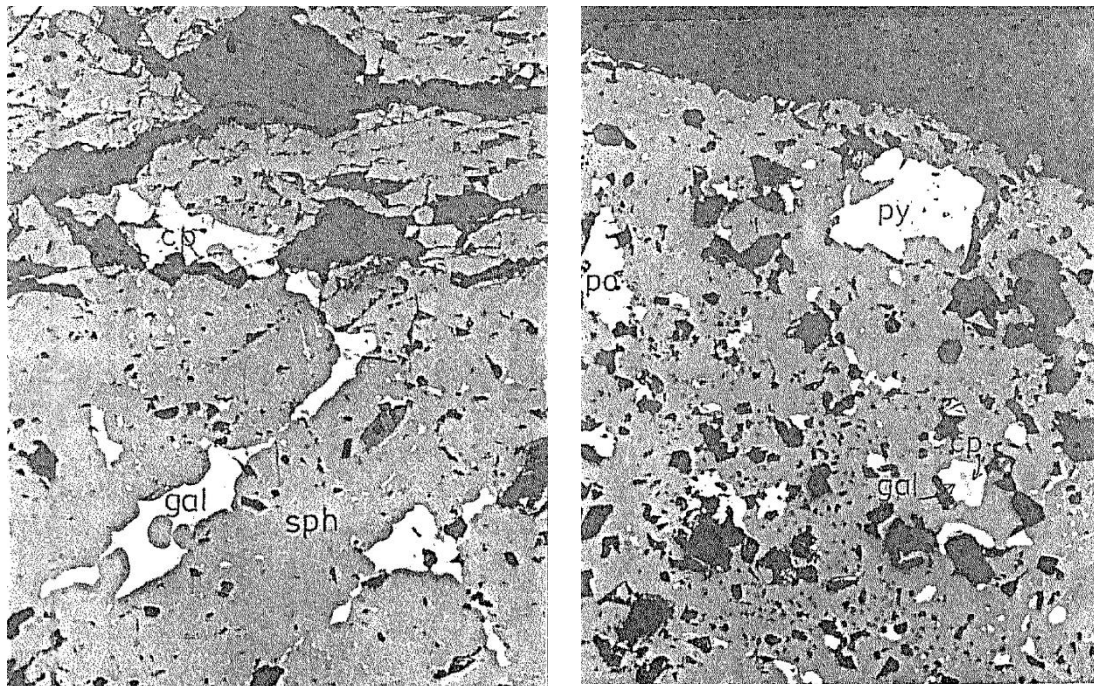


Figure 9. Sphalerite in sample 78B containing irregular veinlets and inclusions of pyrite, pyrrhotite, chalcopryite and galena.

- **#78C**

Essentially the same as 78B, being a silicified and argillised porphyry breccia. Only disseminated cubes of pyrite were noted in thin section, but the hand specimen contains centimetre sized clots of sphalerite and pyrite.

These three final samples represent acid volcanics and associated shallow intrusives that have undergone argillic-phyllic alteration. Zn is a prominent metal in these rocks which are possibly part of an alteration envelope to an epithermal or porphyry stock mineral deposit.

3. Panned concentrate samples

A summary of results from the initial separation, tinning and UV irradiation are given in Table 2. Samples #14-19 which all contain significant scheelite and gold can be related to the Ayllón area from which gold-rich quartz vein samples have been identified above. The scheelite probably has a separate origin within the metasediments that form the country rock. Sample #22, containing cassiterite, is derived from the Peggy mining area. Gold-bearing samples #23, 24, 25 and 28 come from the Zumba area, and #34 and 35 can be related to argillised acid rocks from the Zamora district.

3.1 Gold analysis

Native gold identified in three rock/ore samples and separated from 15 pan concentrates was analysed by electron microprobe. The analyses are given in the Appendix. The alluvial gold grains almost invariably have a thin Ag-leached rim due to the action of ground and/or river water. The analyses quoted represent the compositions of the grain interiors, which duplicate analyses show to be effectively homogeneous, and which should be no different to those possessed by the grains when still entrapped in their host rocks. In addition to analysis for Cu, Au and Ag, native gold in the ore samples was analysed for Sb and Bi. However, these two elements were found to be below detection in all cases.

A feature of all the golds analysed is that Cu is near or below detection level, the exception being one grain in sample 34. Therefore, gold grain chemistry can be portrayed simply by Ag content as shown in Figure 10. It is clear that the gold from the Nambija skarn (~10 atom % Ag) is distinct from gold occurring in the Ayllón polymetallic veins (30-37% Ag). In both these occurrences gold is not accompanied by significant Cu-sulphides and this appears to be reflected by the lack of Cu dissolved in the native gold. It was suggested in the previous report that the presence of significant dissolved Cu usually suggests a Cu-sulphide-gold paragenesis such as a Cu-porphyry or Cu-skarn. With regard to the two Ayllón ore samples, bulk assays indicate a Au/Ag ratio >2, suggesting that Au and Ag abundance can be explained simply by the presence of native gold. That is, there is unlikely to be much Ag contained in other sulphides.

The geographical location of all the pan concentrate samples is not known to the author, however samples 07, 08, 15 and 48 all contain low Ag golds that could be attributable to skarn mineralisation of the Nambija type. The majority of the alluvial golds have higher Ag, negligible Cu and are broadly comparable with the Ayllón vein golds. Two samples, 24 and 25, are distinctly richer in Ag and comparable with samples JACR-3 and JACR-4 analysed previously; compositions compatible with gold (electrum) from epithermal Ag-rich veins.

Table 1. Ore mineral assemblages

Area	Sample	Asp	Pyr	Mar	Cp	Po	Sph	Gal	PbSb	Stan	Wolf	Bis	Gold	Others
Peggy Mine	7A	*	*	*	*	*					*	*		Tour.
	7C	*	*	*		*	*	*		*				
	7D	*	*	*	*	*						*		Tour.
	9													Tour.
	22C													Tour.
Ayllón	25	*	*		*		*	*	*				*	
	27A	*						*					*	
	30		*		*									Mag.
Zumba	38		*											
	43A		*											
	43B		*		*									Covell.
	45		(*)											
Nambija	64C		*		*								*	
	64E		(*)											
	65B		*											
	69		*		(*)									
Zamora	56A		*		*		*							Covell.
	78B		*		*	*	*							
	78C		*				?							

Notes: Asp – arsenopyrite; Pyr – pyrite; Mar – marcasite; Cp – chalcopyrite; Po – pyrrhotite; Sph – sphalerite; Gal – galena; PbSb – boulangerite and bournonite; Stan – stannite; Wolf – wolframite; Bis – bismuthinite and native bismuth.

Tour – tourmaline; Mag – magnetite; Covell – covellite.

Parenthesis = phase is rare

Table 2. Pan concentrate data

Area	Sample #	Mass (grams)	%Mag (1)	%Heavies (2)	Cassiterite (3)	Scheelite (4)	Gold (5)
Burro Playa, etc. area	1	58.1	1.4	84.2			Few large grains
	2	56.3	62.4	33.9		3	
	3A	20.7	42.2	47.5		1	
	3B	23.7	28.0	43.1		?1	
	4	6.1		19.3			
	5A	40.6	<0.2	23.4			Several grains 1 grain Few grains
	5B	4.3		20.9		1	
	5C	32.8	<0.2	33.2			
	5D	62.5		21.2			
	6A	22.4	26.6	45.0		1	
	6B	43.0	22.8	41.9			Several grains 1 grain Few grains
	7	35.5	<0.3	15.5			
	8	23.9	21.8	52.1		2	
	9A	18.4	10.6	51.8			
	9B	50.5	0.4	51.8			
	10A	18.6	<0.5	45.6			Several grains 1 grain Few grains
	10B	33.2	0.3	35.9			
	11	56.4	0.4	30.7			
	12A	77.0	1.7	37.2		?1	
	12B	21.1	<0.5	13.9			
Peggy	13	69.7	46.2	46.1	Few grains Common	30	Several grains
	22	37.5	1.6	48.8			
Ayllón area	14	19.8	13.7	41.1		40	Many tiny grains
	15	34.3	0.9	30.9		10	Many grains
	16A	33.6	4.0	36.4		30	Several tiny grains
	16B	10.3	<1.0	7.0			
	17	26.4	<0.5	20.5		30	3 small grains
	18	43.1	<0.2	42.3		>100	1 small grain
	19	37.8	10.4	46.4		20	1 small grain
	20	10.7	30.5	30.5		6	
Los Planes	21	7.7		33.3		5	
	23	136.5	59.8	34.0		15	1 small grain
	24	261.8	69.5	29.7			4 small grains
	25	156.3	78.0	20.1			1 small grain
	26	42.4	67.3	30.3			
	27	130.2	80.4	14.0			
	28	238.6	68.5	29.4			3 small grains
Malacatos	29	55.6	86.6	10.8			
	30	39.4	0.8	35.2		5	
	31	31.1	<0.3	21.3		?1	
	32	43.3	1.0	10.2		?1	
Piuntza	33	37.6		26.0			
	34	33.2	12.3	11.7			Several small grains
Loja	35	35.9	18.2	43.3			4 small grains
	36A	9.4	19.6	47.8			
Saraguro	36B	45.9		7.3			
	37A	36.4	32.4	52.3			
	37B	114.7	39.2	54.9			
	38	193.6	36.8	49.6			
	39	133.2	24.0	18.3			
Espíritu Playa	40	118.8	24.8	22.6	Common	50	
	41	40.1	6.9	12.9			
	42A	26.1	35.3	18.2			
	42B	189.2	64.8	15.2			
	43	131.6	37.7	19.3			
	44	159.4	61.9	6.5			
	45	73.3	62.3	5.6			
Los Planes Pilares (Río Collay)	46	109.1	14.1	17.1			
	47	2.5					Many tiny grains
	48	1.1					Several small grains
Río Collay (Cabeceras)	49	9.5				2	2 grains

(1) Percentage Magnetite; (2) Percentage concentrate >2.9 density; (3) Results of 'tinning' on non-magnetic fraction;
 (4) Approx. number of grains seen in short wave UV light; (5) Qualitative assessment of no. of gold grains.

3.2 Electron microprobe results for gold

The gold analyses were carried out using the Grant Institute of Geology (University of Edinburgh) Microscan 5 electron microprobe. The analyses given for the alluvial samples represent the internal composition of individual grains. The lower level of detection for Cu is about 0.04 wt.%. The numbers against the ore gold analyses indicate discrete crystals.

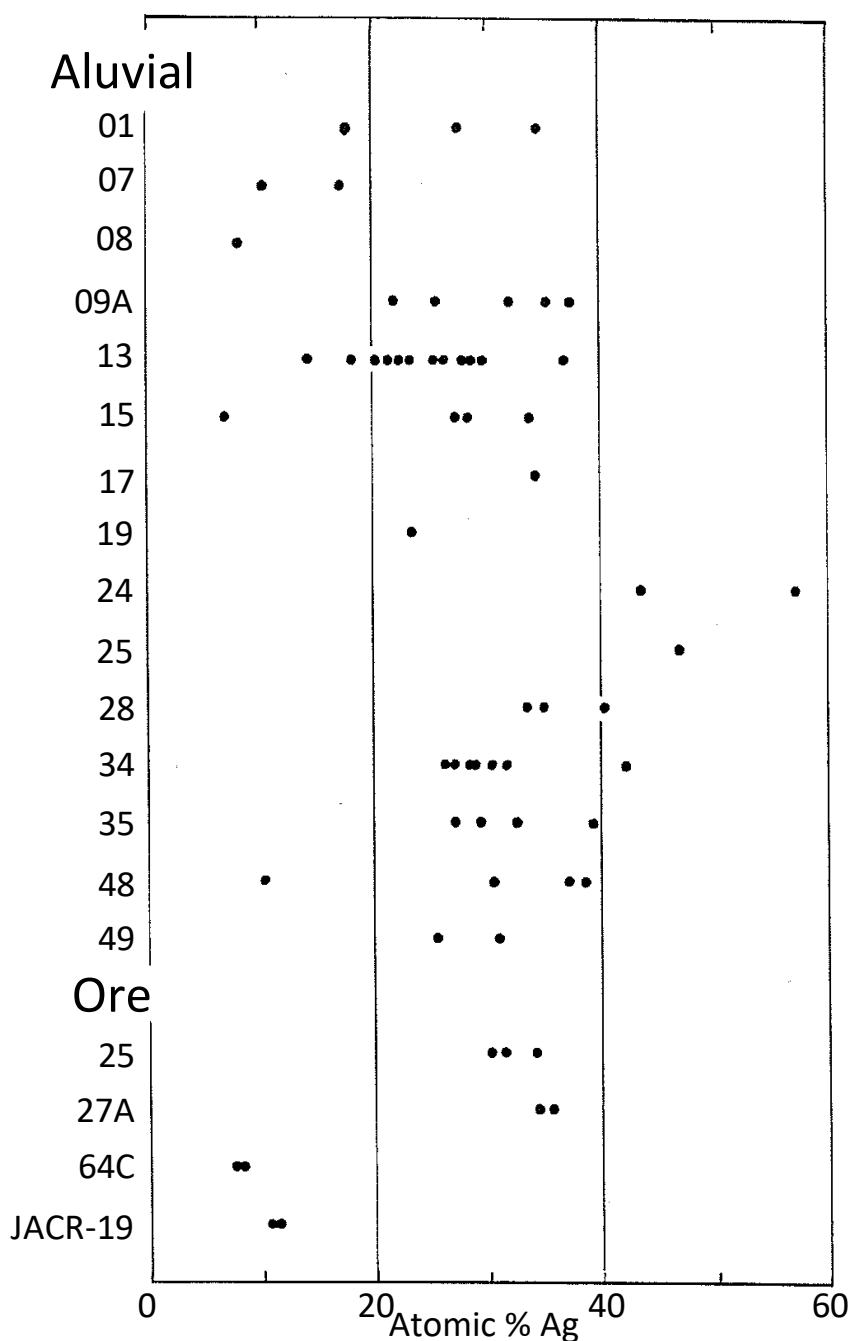


Figure 10. Compositions of native gold from panned concentrates and ore samples. JACR-19 is Nambija skarn analysed previously (Beddoe-Stephens, First Annual Report-Appendix 3, 1987)

Table 3. Alluvial gold composition

Sample	Grain	Au WT % E	Au ATOM	Ag WT % E	Ag ATOM	Cu WT % E	Cu ATOM
CR-MC-P-01	1	82.88	72.438	17.27	27.562	0.00	0.00
	2	77.33	65.426	22.38	34.574	0.00	0.000
	3	89.54	82.493	10.39	17.479	0.01	0.029
CR-MC-P-07	1	90.47	83.042	10.05	16.844	0.04	0.114
	2	94.20	89.784	5.87	10.216	0.00	0.000
CR-MC-P-08	1	95.99	91.702	4.74	8.268	0.01	0.030
CR-MC-P-9A	1	86.53	78.072	13.31	21.928	0.00	0.000
	2	77.11	64.919	22.82	35.081	0.00	0.000
	3	75.13	62.802	24.32	37.121	0.03	0.078
	4	79.27	68.010	20.42	31.990	0.00	0.000
	5	83.80	74.397	15.76	25.548	0.02	0.055
CR-MC-P-13	1	88.91	81.804	10.78	18.111	0.03	0.086
	2	81.18	70.459	18.64	29.541	0.00	0.000
	3	82.07	72.160	17.29	27.759	0.03	0.082
	4	83.90	74.436	15.78	25.564	0.00	0.000
	5	91.14	85.595	8.40	14.405	0.00	0.000
	6	82.30	72.120	17.39	27.826	0.02	0.054
	7	86.46	77.218	13.97	22.782	0.000	0.000
	8	74.14	63.109	23.65	36.759	0.05	0.132
	9	85.49	76.754	14.18	23.246	0.00	0.000
	10	87.66	78.721	12.96	21.251	0.01	0.028
	11	80.46	70.948	18.01	28.998	0.02	0.055
	12	88.86	79.942	12.21	20.058	0.00	0.000
CR-MC-P-15	1	77.75	66.072	21.78	33.796	0.05	0.132
	2	96.69	92.987	3.96	6.954	0.02	0.060
	3	82.18	71.857	17.61	28.116	0.01	0.027
	4	82.14	72.962	16.67	27.038	0.00	0.000
CR-MC-P-17	1	77.87	65.825	22.09	34.096	0.03	0.079
CR-MC-P-19	1	85.36	76.877	14.01	23.039	0.03	0.084
CR-MC-P-24	1	57.94	43.007	42.05	56.993	0.00	0.000
	2	69.98	56.608	29.36	43.367	0.01	0.025
CR-MC-P-25	1	67.05	53.091	32.36	46.787	0.05	0.123
CR-MC-P-28	1	72.06	59.954	26.36	40.046	0.00	0.00
	2	78.18	66.540	21.53	33.460	0.00	0.000
	3	76.70	65.515	22.11	34.485	0.00	0.000
CR-MC-P-34	1	79.84	68.219	20.37	31.781	0.00	0.000
	2	83.67	72.951	16.99	27.049	0.00	0.000
	3	82.28	71.805	17.66	28.141	0.02	0.054
	4	83.63	72.648	16.48	26.140	0.45	1.212
	5	82.13	71.204	18.19	28.796	0.00	0.000
	6	71.04	57.947	28.20	42.002	0.02	0.051
	7	80.70	69.927	18.99	30.046	0.01	0.027
CR-MC-P-35	1	82.54	72.705	16.97	27.295	0.00	0.000
	2	73.32	60.820	25.85	39.154	0.01	0.026
	3	81.93	70.820	18.42	29.073	0.04	0.107
	4	78.47	67.267	20.81	32.573	0.06	0.159
CR-MC-P-48	1	94.78	89.892	5.82	10.079	0.01	0.029
	2	75.10	62.809	24.32	37.139	0.02	0.052
	3	73.74	61.339	25.42	38.610	0.02	0.052
	4	79.95	69.490	19.19	30.456	0.02	0.054
CR-MC-P-49	1	79.39	69.279	19.28	30.721	0.00	0.000
	2	83.74	74.448	15.74	25.552	0.00	0.000

Table 4. Ore gold composition

Sample	Grain	Au WT % E	Au ATOM	Ag WT % E	Ag ATOM	Cu WT % E	Cu ATOM
CR-MC-25	1	80.64	69.381	19.49	30.619	0.00	0.000
	2	78.09	68.727	19.46	31.273	0.00	0.000
	3	78.83	69.531	18.85	30.359	0.04	0.109
	4	74.28	65.882	21.05	34.091	0.01	0.027
	5A	79.20	69.509	19.01	30.464	0.01	0.027
	5B	78.41	68.511	19.72	31.462	0.01	0.027
	6	76.92	65.860	21.82	34.114	0.01	0.027
CR-MC-P-27A	1A	76.58	65.349	22.17	34.545	0.04	0.106
	1B	76.81	65.330	22.29	34.618	0.02	0.053
	2	76.17	64.247	23.18	35.701	0.02	0.052
CR-MC-P-64C	1A	95.30	91.889	4.59	8.081	0.01	0.030
	1B	94.71	91.861	4.46	7.899	0.08	0.241

Acknowledgements

Roy Fakes did the mineral separation work and prepared the polished gold grain slides.

Reference

BEDDOE-STEPHENS B. (1987) A pilot examination of alluvial and in situ gold and platinum from Ecuador. Mineralogy & Petrology. Report 87/3. (BGS, Edinburgh).

APPENDIX 7

MINERALOGY AND PETROLOGY

Report No. WG/88/17R

Petrography of some granites from the Cordillera Real, Ecuador

by

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25 august 1988

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Petrography of some granites from the Cordillera Real, Ecuador

J. Dangerfield

1. Introduction

Sixteen samples of coarse to medium grained poorly megacrystic granites, and their cataclastically deformed equivalents, were submitted by Dr. J. Aspden of the Overseas Directorate.

Individual descriptions of the samples are presented together with a table of modal analyses of the undeformed and least deformed specimens. The report is concluded with some observations on granite type and a sequence of progressive deformation features.

2. Specimen descriptions

- **CR-FV-315. Río Minas-Tres Lagunas pluton**

An augen schist or sheared granite in which the schistosity is defined by alternating bands of quartz and micaceous material. The quartz-rich bands average 1 to 2 mm in width, the micaceous bands less than 0.5 mm, both being sub-parallel and undulating. The augen are formed principally by orthoclase and microcline-microperthite megacrysts, with a few of quartz and plagioclase, many of which are strained. They range in size from about 2 to 10 mm. Additionally granite clasts are visible in the hand specimen, and all the augen deflect the schistosity.

The felsic bands consist almost entirely of an interlocking mosaic of quartz 0.2-0.4 mm in size, with a few larger crystals of plagioclase, and scattered flakes of muscovite.

The micaceous bands consist principally of elongate muscovite flakes oriented parallel or sub-parallel to one another and to the margins of the bands. Some bands contain olive to olive-brown biotite normally at their margins, and where biotite is common the bands are dusted with finely divided opaque iron oxide. Associated with the biotite-bearing bands are trains and aggregates of euhedral to subhedral zoisite, and this mineral occurs together with sericite as an alteration product of plagioclase. Rare garnets are also embedded in the micaceous bands and in places wispy trains of late-stage hematite occur.

- **CR-FV-330. Río Negro-Tres Lagunas pluton**

A coarse-grained granite with a few small megacrysts of quartz and feldspar ranging from 5 to 10 mm in size. The rock consists essentially of quartz, potassium feldspar, plagioclase, biotite and a little muscovite.

Quartz is present as rare megacrysts, aggregates of interlocking grains and as interstitial patches of fine grain size. All the crystals are anhedral and most show a little strain.

Plagioclase occurs mainly in subhedral and euhedral about 2 to 4 mm in size. One crystal in the section exceeds 8 mm in length so the small megacrysts noted in hand specimens are probably of plagioclase. The mineral is extensively sericitised but appears to be in the albite range. The potassium feldspar consists of interstitial anhedral and subhedral of orthoclase and microcline with rare larger crystals, up to 3 mm in size of perthite.

The principal mica is biotite in rather ragged subhedral 0.5 to 3 mm in length, a few crystals showing slight alteration to penninite. Most of the crystals contain minute radioactive minerals which have pleochroic haloes, and some biotites have inclusions of apatite. Muscovite is generally an alteration product of biotite, but some crystals may be primary.

Accessory minerals include zircon, apatite, sphene and garnet. Zircon is associated with biotite and probably produces the pleochroic haloes in that mineral. The larger crystals are euhedral to subhedral, 0.04-0.08 mm in size. Sphene is also generally associated with biotite, although a few crystals occur scattered elsewhere in the rock. Garnets are subhedral 0.08 to 0.2 mm in size and almost invariably occur as inclusions within plagioclase. Moreover, they are concentrated in some of the plagioclase crystals, others being free from garnet.

The texture of the rock is coarse hypidiomorphic granular with an average groundmass grain-size of about 2 mm.

The hand specimen contains a small xenolith of feldspar-porphyry or microporphyritic rhyolite.

- **CR-FV-332. Río Negro-Tres Lagunas pluton**

A sheared granite with a generally streaky appearance defined by 1 to 3 mm wide intermittent foliae of mica which are deflected around deformed quartz and feldspar augen.

The augen are mainly formed by plagioclase with a few examples of orthoclase and quartz. These were probably small megacrysts in the undeformed rock. Many appear to have retained their original sizes but have rather ragged outlines. The lamellar twinning of the plagioclase has been considerably disturbed. The lamellae remain straight but have been broken irregularly and transversely. On rotation of the stage, crystals extinguish in vaguely outlined domains rather than in the normal mode for lamellar twinning, although undeformed portions of these crystals do occur. The quartz megacrysts have escaped destruction but show strain effects, in some cases by marked undulose and radial extinction.

Groundmass plagioclase crystals are little affected by the lamellar disruption, and the few potassium feldspars remain undeformed. Groundmass plagioclases are commonly sericitised but it is noteworthy that those forming augen are not. Quartz occurs in irregular bands or segregations as a mosaic of interlocking crystals 0.2 to 0.6 mm in size.

The larger mica crystals, originally about 1.5 mm across, have been severely disrupted and now consist of aggregates of fine-grained biotite or biotite and muscovite with extensive development of zoisite. The remaining mica occurs as wavy intermittent foliae of biotite, muscovite and zoisite with associated rare sphene and garnet. Some of the foliae consist mainly of fine-grained muscovite and euhedral zoisite with plagioclase fragments and probably represent the extreme stage of disruption of groundmass plagioclase crystals.

- **CR-FV-334. Corral Huayco-Tres Lagunas pluton**

This is a coarse, even-grained granite with much quartz visible in hand specimen.

Thin section examination confirms the presence of abundant quartz, a little microcline-microperthite and extensively sericitised plagioclase.

Much of the quartz is in the form of large crystals which show strain, but in many places, particularly at the boundaries between large plates and adjacent to micaceous aggregates, bands or irregular areas of fine-grained interlocking crystals have formed.

The potassium feldspar occurs as a few large crystals while plagioclase, in the albite range, is more evenly distributed. Although extensively sericitised a few small crystals of the latter mineral and some small areas of larger crystals are almost entirely free from this alteration.

Distributed fairly evenly throughout the rock are aggregates of mica, chiefly biotite, which are the recrystallised remains of biotite plates formerly 0.3 to 0.5 mm in size. Many of the aggregates contain streaky relics of the original biotite plates, the cleavage distorted and lined with dusty opaque iron oxide. Newly grown crystals of biotite commonly cut across the cleavage of original crystals, parts of which are replaced by muscovite. In many cases there are extensive developments of euhedral to subhedral zoisite. Sphene, apatite, opaque iron oxide, rare cordierite and garnet are present within the mica aggregates. Zoisite is an alteration product of some plagioclase crystals and garnet occurs in clusters within this feldspar in places.

The rock is coarse-grained, with a mean size of from 0.2 to 0.4 mm and, apart from the recrystallisation described retains an essentially hypidiomorphic granular texture.

- **CR-FV-355. La Palizada-Tres Lagunas pluton**

This is an augen schist or sheared granite with streaks of micaceous material enveloping augen of feldspar and quartz.

The augen are fairly regularly distributed, 1 to 3 or rarely 5mm in size, and surrounded by sub-parallel felsic and micaceous schistose foliae.

Most of the augen are formed of single crystals of plagioclase, many being elongated parallel to the schistosity. In some cases, lamellar twinning has been destroyed but where present the mineral appears to be in the albite-oligoclase range. A few of the augen consist of potassium feldspar or quartz and feldspar aggregates. Where augen are equant, quartz has crystallised in the pressure shadow areas adjacent to augen crystals.

The remainder of the rock consists of continuous quartz-feldspathic bands, interspersed with wavy discontinuous micaceous foliae. The felsic bands, in which much of the quartz, the major constituent, and some of the feldspar, is elongated parallel to the schistosity, has a mean grain size of about 0.5 mm. The micaceous foliae consist of biotite, muscovite and penninite elongated parallel to the schistosity, with streaks and blebs of dusty opaque iron-oxide.

Calcite is scattered unevenly throughout the felsic bands and occurs particularly with quartz in the pressure shadow areas adjacent to the augen, a little being seen within these relict crystals themselves. Although disposed in elongate areas parallel to the schistosity, cleavage and twin lamellae of the calcite are both undeformed, indicating that the mineral crystallised after release from the principal period of stress.

Zircons are common within a few of the larger biotite crystals, where they have caused radioactive haloes to form, and garnet is a rare accessory.

- **CR-FV-358. Río Shio-Tres Lagunas pluton**

Augen schist or sheared granite with augen of feldspar. This rock is similar to CR-FV-355, but has smaller and more plentiful augen, a finer grain-size in the felsic bands (mean about 0.2 mm) and a greater proportion of micaceous material disposed in more persistent bands than those of the former sample. The mica is muscovite or very pale brown biotite and no chlorite is present. Zircon occurs sporadically in the quartz-feldspathic bands. A few crushed garnets are present in the micaceous bands.

- **CR-FV-359. Gima-Cuyes**

This is a sheared granite with a streaky appearance; the streaks being defined by foliae of micaceous minerals. The hand specimen is slightly stained with iron-oxide. A coarse-grained granitic rock with small megacrysts of feldspar set in a groundmass of quartz, feldspar and a little scattered muscovite. The groundmass has been disrupted and recrystallised and is penetrated by sub-parallel foliae of muscovite crystals.

The feldspar megacrysts are mainly of orthoclase and microcline-microperthite but with some sericitised plagioclase in the albite-oligoclase range. The groundmass feldspars are both plagioclase and potassium feldspar and are aggregated in some areas. Likewise, the quartz has been formed into rudimentary bands of recrystallised interlocking grains, 0.2-0.6 mm across.

The mica is all muscovite and has recrystallised into quite definite but impersistent and undulating foliae, only a few percent of that mineral remaining in the groundmass. Irregular bands of opaque iron-oxide are associated with the muscovite foliae and occur along grain boundaries elsewhere. One feldspar megacryst has been broken into three portions, the breaks being invaded by muscovite foliae.

A few zircons and a little blue tourmaline are present. Cordierite occurs in subhedral and is slightly altered to muscovite. Garnet is a rare accessory mineral. Some granitic textural features remain, but the groundmass has been largely recrystallised. The absence of biotite suggests that the rock may have been greisenized prior to deformation.

- **CR-FV-389A. Río Collay**

An augen schist with prominent and plentiful augen of feldspar up to 10 mm in length set in a dark groundmass.

The rock contains many augen, mainly of feldspar or quartz single crystals, but also of quartz aggregates. Augen range from 0.1 to 0.4 mm in length as seen in thin section, and are commonly elongated in the direction of the schistosity.

The groundmass between the augen is occupied by irregular but generally persistent foliae of mica and chlorite, which wrap themselves around the augen, together with a mosaic of recrystallised quartz. Only a little plagioclase remains in the groundmass.

The micaceous foliae consist mainly of muscovite, with minor wispy biotite flakes and impersistent elongate zones of penninite. The bands are streaked with small blebs of opaque iron-oxide and much of the muscovite is very fine-grained. A few zircons are embedded in the micaceous foliae and some of the few remaining biotite crystals still contain inclusions with accompanying pleochroic haloes. Accessory garnet is also present. Muscovite is scattered throughout the quartz mosaic, and in some areas, calcite is abundant in single crystals or as aggregates. Lack of disruption of cleavage and twin lamellae suggests that this mineral crystallised after the imposition of the schistosity. The mosaic of quartz and calcite has a mean grain size of about 0.2 mm.

The granitic texture of this rock has been virtually destroyed, only the quartz and feldspar augen, which may represent former small megacrysts, remain of the original fabric of the rock.

- **CR-FV-493. Malacatos basin north**

A medium grained granite with small quartz and feldspar megacrysts, and interstitial fine-grained areas. The feldspar megacrysts are of orthoclase-microperthite and range in size from 3 to 5mm. Quartz megacrysts are about 5 mm in size.

The medium grained portion of the groundmass consists of quartz, plagioclase, potassium feldspar, biotite and muscovite. Quartz is anhedral and most of the plagioclase is sericitised. Some of the biotite has been altered to muscovite but no chlorite is present. The mean size of this portion of the groundmass is about 1 mm.

The finer grained portions of the groundmass consist of mosaics of quartz with small scattered flakes of biotite and muscovite. These areas have a mean grain size of 0.1 to 0.2 mm and may represent the earliest phase of response of the granite to stress.

Euhedral to anhedral garnet is the principal accessory mineral and is scattered unevenly throughout the rock. A little opaque iron-oxide is associated with the biotite.

With the exception of the fine-grained areas noted, the rock presents a typical hypidiomorphic granular texture characteristic of granites.

The hand specimen contains a quartz rich xenolith 40 mm in size which may be part of a lode or a metamorphic quartz-segregation.

- **CR-FV-493B. Malacatos basin north**

A medium grained granite with small quartz and feldspar megacrysts up to 10 mm in size.

The rock is similar to CR-FV-493, but with less fine-grained quartz rich mosaic. There are two small xenoliths of sheared granite in the thin section. Both are rich in mica, much of its biotite altered to muscovite. Zoisite is abundant in small patches. The larger quartz megacrysts seen in hand specimen may well be xenocrysts.

- **CR-FV-498. Malacatos basin north**

This is a poorly megacrystic medium grained granite which has suffered incipient shearing. It contains one feldspar megacryst about 30 mm in length and a few smaller examples.

The one 30 mm megacryst is encountered in the thin section, and is a plagioclase (oligoclase range) which has been almost entirely replaced by potassium feldspar, (orthoclase microperthite). Most of the groundmass feldspar is extensively sericitised albite although a few crystals are almost entirely free from alteration. In a few examples their lamellar twinning has been distorted.

Some of the quartz is in fairly large crystals, about 2 mm in size, but much of this mineral occurs in aggregates, each forming a mosaic of interlocking grains. All the larger crystals and some of the smaller ones show strain.

Originally the biotite was in the form of discrete crystals about 2 mm in size and some of these remain, although wholly or partly altered to muscovite and with distorted cleavage. Much of the biotite however, occurs as fine-grained aggregates and as foliae with associated muscovite. These irregular and undulating foliae also contain blebs of opaque iron-oxide, sphene, zoisite and a little garnet. Some of the biotite has been altered to penninite but in the freshest flakes minute inclusions, probably of zircon, show pleochroic haloes. A little accessory garnet occurs as inclusions within plagioclase. Some of the larger anhedral sphene is arranged in coronae around irregular opaque iron-oxide crystals.

The overall mean groundmass grain size is about 0.7 mm. The texture is hypidiomorphic granular but has been disrupted by the formation of the non-penetrating foliation.

- **CR-FV-602B. Malacatos basin south**

A sheared granite, with a few small megacryst relics, which is traversed by a 2 to 4 mm wide zone of intense deformation.

No megacrysts are present in the thin section. Most of the feldspar is plagioclase, albite in composition. Much of this albite is extensively sericitised but some crystals are almost free from alteration. In both cases the albite twin lamellas have been bent or curved and, in many places, broken. The fractures may be straight or curved or irregular and do not follow any particular direction in the rock. In some plagioclases a little zoisite is developed along with the sericitisation. Very little potassium feldspar is present.

A few relatively large quartz crystals occur and these show strain, but most of the quartz forms large areas of interlocking mosaic divided by plagioclase and the foliae of micaceous minerals.

A number of the original plates of biotite are present, many now a pale shade of brown. Their cleavage has been curved and distorted. Many of the crystals are dusted with opaque iron-oxide and some show extensive alteration to zoisite. In a few places, epidote is developed and some crystals are partly altered to penninite. Much of the biotite is dispersed in foliae which wrap around plagioclase and quartz aggregates, and in places penetrate the quartz mosaics and fractured feldspars. Other recrystallised biotite forms irregular areas in association with muscovite and zoisite. In places recrystallised biotite cuts across the distorted cleavage of original crystals. A few garnets are present. Although the rock has been extensively recrystallised some relics of granite texture remain.

A fine-grained zone of intense deformation cuts right across both relict igneous and metamorphic fabrics of the rock and is therefore probably of late formation. The zone is composed principally of fine to very fine-grained granular quartz with extensive trains and aggregates of zoisite. It also includes foliae of muscovite and scattered biotite flakes.

- **CR-RB-76. Palora-Huamboya watershed**

The hand specimen is mainly of coarse-grained granite. Quartz is present in large 2 mm wide plates and in areas of interlocking crystals forming a fine-grained mosaic, most of the grains showing evidence of strain.

The principal feldspar is extensively sericitised plagioclase although some orthoclase and microcline microperthite is also present.

Biotite occurs in equant subhedral distributed rather unevenly throughout the rock. It is not distorted but the margins of crystals are rather ragged and show incipient alteration to a fine-grained aggregate of muscovite, epidote and zoisite. Biotite is chloritised in a few places and has inclusions of apatite and zircon. A little muscovite is associated with biotite, and garnet is a rare accessory.

The rock has a coarse hypidiomorphic granular texture with a mean grain size of about 2 mm.

Included in the specimen is a fine grained dark grey xenolith. This consists of small plagioclase and quartz megacrysts set in a fine-grained groundmass of quartz, plagioclase and biotite with a little scattered muscovite. All the plagioclase is extensively altered to sericite, zoisite and a fibrous mineral, commonly occurring in radiating sheaves, which may be actinolite. Plagioclase encloses a few garnets and zircons.

Biotite occurs as discrete well-formed crystals evenly distributed throughout the rock, but most of it has suffered marginal alteration to epidote. Inclusions of zircon are very rare.

- **CR-RB-223. Alao pluton**

A coarse-grained biotite rich granitic rock, which also contains segregations or schlieren of biotite, up to 15 mm across. Quartz occurs in large plates, up to 5 mm in size, which show considerable strain, and as an interlocking mosaic of crystals 1 to 2 mm in size. Plagioclase megacrysts attain a length of 15 mm, and the mineral also occurs in the groundmass. Almost all crystals are extensively sericitised, and altered to abundant zoisite and in places to a fibrous radiating mineral possibly actinolite. Alteration makes the plagioclase difficult to determine but it appears to be albite. Very little potassium feldspar is present.

Biotite is present in aggregates with crystals commonly 4 to 5 mm in size. In places it is extensively altered to muscovite and rarely chloritised. Associated with the biotite aggregates are large (1 mm diameter) garnets, clusters of zoisite crystals, blebs and strings of opaque iron-oxide, apatite, zircon and epidote. Zoisite and epidote appear to be replacing biotite, marginally and along internal cracks.

The texture is hypidiomorphic granular with a mean groundmass grain size of about 2 mm.

- **CCR-E-87-14. Peggy Mine**

A poorly megacrystic granite which has suffered incipient cataclastic deformation. Potassium feldspar megacrysts up to 30 mm in length are visible in hand specimen.

The megacrysts, although internally disturbed, appear to be orthoclase micropertthite. The groundmass feldspar is mainly plagioclase, albitic in composition, which has been extensively sericitised. In some crystals the twin lamellae are curved, and others contain numerous small euhedral to subhedral garnets.

Quartz occurs in strained crystals, 1 to 2 mm in size, which are commonly granulated at their margins, and in recrystallised interlocking mosaics.

Biotite occurs in aggregates. Original crystals, about 2 mm in size, remain but have distorted cleavage and ragged margins. A little biotite has been replaced by muscovite but otherwise no recrystallisation of this mineral occurs. Some of the biotite is green but there is little chloritisation. Inclusions of apatite, sphene and opaque iron-oxide are common, but zircon is rare. In some biotite clusters spectacular coronae of sphene, 0.5 mm in diameter, surround anhedral of opaque iron-oxide.

One somewhat granulated tourmaline was noted.

The texture of the rock is hypidiomorphic granular cataclastically deformed. One biotite rich cluster about 20 mm in size may be the remains of a xenolith.

- **CCR-E-87-14A. Peggy Mine**

A blue grey megacrystic granite which has suffered incipient cataclastic deformation. The hand specimen contains one potassium feldspar megacryst more than 30 mm in length.

The groundmass feldspar is extensively sericitised albite with a little potassium feldspar. Small euhedral garnets are common inclusions in plagioclase and in some cases the feldspar has developments of zoisite. Some of the quartz occurs in crystals 1 mm or less in size, strained and granulated at the margin, but much of this mineral is in the form of mosaics of interlocking crystals 0.05 to 0.2 mm in diameter.

Biotite occurs as single crystals and in aggregates or clusters. The mineral is greenish brown and is altered to penninite in places. The cleavage is commonly distorted and crystal margins are ragged. Some alteration to muscovite occurs but there is no new biotite. Inclusions of apatite, opaque iron-oxide and sphene are common, the latter forming coronae up to 0.5 mm in diameter around the iron-oxide. A few minute inclusions have radioactive haloes and a little garnet is associated with the biotite. The texture is coarse grained hypidiomorphic granular, with a mean groundmass grain size of 2 to 3 mm.

3. Modal analysis

Modal analyses were carried out on thin sections of eight specimens; 1000 points being counted in each case. The results are as follows:

Sample No.	330	334	493	493B	602B	76	223	14A
Quartz	33.7	57.8	57.8	49.9	39.6	41.9	35.4	45.8
K-feldspar	13.1	10.9	6.1	2.1	3.4	0.7	0.4	5.4
Plagioclase	34.9	13.6	15.1	26.9	29.8	40.0	40.7	31.5
Biotite	15.2	13.9	11.6	12.1	18.6	11.7	15.1	9.0
Muscovite	2.3	1.0	8.5	8.5	3.6	3.6	5.2	3.7
Chlorite	0.2	1.7	-	-	1.2	0.2	0.4	3.7
Zoisite	tr	0.5	-	tr	3.8	1.6	0.3	0.1
Apatite	0.1	tr	-	-	-	0.1	0.2	0.3
Garnet	0.3	0.3	0.8	0.5	tr	tr	2.0	0.3
Sphene	0.2	0.2	-	-	-	tr	0.2	0.2
Opaque oxide	tr	0.1	0.1	tr	tr	0.2	0.1	tr
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

tr (trace) indicates that the mineral was seen in thin section but not counted.

4. General comments

4.1 Granite types

Although the principal distinctions between I-type and S-type granites are chemical, some petrographical features, which reflect the differences in chemical composition, can be used as indicators of granite type. (Chappell and White, 1974).

The following features would indicate that the granites are S-type:

- (1) All the rocks are granites *sensu stricto* and modal quartz is high so that SiO₂ is most probably high.
- (2) Biotite is present to the exclusion of hornblende.
- (3) Modal biotite is high.
- (4) Muscovite is present in all the granites and relatively abundant in some.
- (5) Garnet is present in all the specimens and cordierite occurs in two samples.
- (6) In a few specimens apatite occurs as discrete crystals.

Conversely, there are two features which might be taken to indicate I-type:

- (1) In some samples apatite occurs as inclusions in biotite.
- (2) Spinel is present in some specimens, although probably as an alteration product, whereas monazite was not recorded.

On petrographical grounds alone, the suite would seem to be of S-type.

4.2 Progressive cataclastic metamorphism

Even though the number of specimens is limited, it is possible to divide them into small groups which seem to exhibit stages in the progressive cataclastic metamorphism of granite. It is tentatively suggested that petrographical features might be used to define a sequence of stages in such progressive metamorphism. Mineralogical transformations characteristic of dynamic metamorphism begin before any important textural modifications occur. Among the earliest of these are the sericitization of feldspars and the production of zoisite from plagioclase (Harker, 1960, pp. 273-274).

Recrystallisation can also occur at an early stage and, as stress increases, is followed by more purely mechanical transformations, alongside which it can continue to a late stage.

With regard to this set of granite specimens, the following sequence of stages can be built up:

- (1) Some recrystallised quartz mosaic.
Plagioclase sericitised and altering to zoisite.
- (2) Considerable development of recrystallised quartz mosaic.
Biotite ragged and marginally recrystallised; cleavage distorted.
- (3) Quartz mosaic complete.
Mica cleavage distorted; some recrystallisation.
Feldspar lamellar twinning bent or broken.
Non-penetrating mica foliae developed.
- (4) Quartz mosaic forms well developed laminae.
Mica disrupted and/or partly recrystallised.
Definite augen formed.
Penetrating mica foliae developed.
- (5) Continuous quartz laminae developed.
Mica foliae complete.
Augen well-formed commonly with pressure shadows.
Complete schistosity developed.

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APPENDIX 8

NATURAL ENVIRONMENT RESEARCH COUNCIL
SCIENTIFIC SERVICES

ISOTOPE GEOLOGY CENTRE
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Report No. NIGC 88/7

Potassium - Argon ages for minerals from the Cordillera Real, Ecuador

by

C. C. Rundle

Fourth progress report documenting work undertaken for the ODA/BGS-
commissioned Cordillera Real Geological Research Project

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1. Introduction

This report presents the results of K-Ar dating of 75 mineral concentrates separated from suites of rocks collected in Ecuador in June and July 1987. Previous reports in this series were concerned with: 1) a pilot K-Ar dating study of mineral separates provided by the BGS collaborators in Ecuador (BGS Isotope Geology Unit Report 87/5); 2) documentation of the field sampling programme (IGU 87/12); and 3) a discussion of the results of the Rb-Sr analysis of these samples (NIGC 87/1).

In a few cases the K-Ar results presented here are new data obtained for samples which were not amenable to Rb-Sr dating, but the majority are on minerals separated from the same samples as those used in the Rb-Sr study, so that a comparison may be made between the two methods as an aid to the interpretation of the earlier results, and in order to obtain information about the subsequent history of these rocks after emplacement. It must be noted that this report is written for the benefit and assistance of the field geologists who commissioned the study and thus concentrates on interpretation of the data in terms of reliability and significance. It is intended that this report, together with the earlier one on the Rb-Sr dating, will be incorporated in a joint paper which will relate the isotopic data to the geological evolution of the area.

As with the earlier study, the poor exposure and high degree of weathering in the Cordillera Real made selection and collection of samples in the field a rather haphazard affair, and a subsequent lack of detailed petrographic descriptions made selection of samples for mineral separation a somewhat arbitrary process. Consequently, in some cases the data interpretation is difficult and subjective; hopefully this can be improved when the petrographic study has been completed. It is evident from some of the results that some minerals were mis-identified in the field and in several cases extensively altered material has been analysed.

Moreover, because of the time constraints and lack of support staff in the Gray's Inn Rd laboratories, preliminary mineral separations were carried out in Ecuador. This necessitated a simple procedure to be set up and a somewhat arbitrary decision to be made at an early stage as to a suitable grain size to be used. Unfortunately, subsequent examination revealed that in some cases the individual crystals were smaller than the grain size chosen so that composite grains were analysed. In most cases the contaminating material was quartz, which is inert as far as K-Ar dating is concerned and should not affect the age - but it does affect the homogeneity of the sample and hence the reproducibility of the analyses.

Nevertheless, despite these problems, it is considered that sufficient data have been obtained so that anomalous results can be identified and rejected, and the majority of samples give meaningful results which add to the understanding of the development of the rocks of the Cordillera Real area.

2. Analytical details

In Ecuador a preliminary separation of mafic from felsic minerals was effected using heavy liquids, and strongly magnetic Fe-rich species were removed with a hand magnet. The weakly magnetic, mafic fraction only was shipped to the Isotope Geology laboratories in London. After microscopic examination the mineral concentrates were further purified using a series of calibrated, intermediate density mixtures of Di-iodomethane and Tri-ethyl-ortho-phosphate, followed by electro-magnetic separation in a Frantz magnetic barrier separator. Potassium was determined, at least in duplicate, using an Instrumentation Laboratories IL543 flame photometer with Lithium as the internal standard. Replicate determinations of in-house standards suggest that an overall precision of $\pm 1\%$ (1 sigma) is realistic for most samples, even though some duplicates may reproduce better than this. Values for international standards are normally within this error of the accepted value.

In the case of some altered and inhomogeneous samples the duplicate determinations were outside this range and so further analyses were made. The error quoted in the table of results, and used in the calculation of the error on the age, is the standard error of these measurements.

Argon was extracted by fusion under vacuum using external radio-frequency induction heating and analysed by the isotope dilution method in a VG Isotopes MM1200 mass spectrometer. The error on the radiogenic argon determination shown in the table is partly dependent on the amount of contaminating atmospheric argon, which often reflects the degree of deuteric alteration and hence varies considerably between different samples. The argon spike system was calibrated against international standards and so the results can be expected to be accurate within the limits of the analytical error. In cases where a coexisting suite of samples were analysed and a particular result appeared anomalous then a second aliquot was analysed as a check on accuracy and reproducibility. These results are documented in the table of analytical results at the end of this report.

Ages were calculated using the decay and other constants recommended by Steiger and Jager, (Earth Planet. Sci. Lett. 36, 359-362, 1977.) and the errors on the ages are quoted at the 95% confidence level.

3. Discussion of results

3.1 Pimampiro diorite

Coexisting hornblende and biotite from sample 1A show good agreement in age, with a mean of 81 ± 3 Ma. This is probably reflecting a real geological event, either rapid cooling after intrusion or complete resetting during a major reheating event, since if slow cooling or partial disturbance of the isotopes were involved then the two mineral systems would have behaved differently and would not have given the same age. It must be noted, however, that the biotite sample has a relatively low K content suggesting partial alteration to chlorite (this should be confirmed by examination of thin sections) and thus is likely to have suffered some argon loss - so the coincidence of the ages may be fortuitous. Muscovite from an apparently cross-cutting pegmatite vein (sample 1B, from a loose boulder in a stream) is significantly younger at 50 ± 3 Ma; presumably reflecting later hydrothermal activity.

The results from sample 1C, however, show a significant difference between the two minerals. The apparent age for the hornblende is older than that for 1A whilst that for the biotite is younger. Since it is known that the blocking temperature for argon diffusion is higher in hornblende than in biotite it is suggested that this pattern of apparent ages may indicate either slow cooling or incomplete resetting in this sample. It must be noted that sample 1C was collected some ten kilometres away from 1A, on the other side of a valley, and there is no guarantee that both are from the same pluton. Moreover, it is a much coarser rock with large megacrystic amphiboles and it is possible that it had a significantly more protracted cooling rate than 1A.

Thus, it is impossible to say whether the discordant results for 1C are due to partial overprinting or slow cooling but, in either case, it is likely that the original age of emplacement was greater than ca. 90 Ma. The data from 1A might imply that final cooling (or resetting) took place at around 80 Ma and it would appear that subsequent reheating, possibly associated with pegmatite injection at ca. 50 Ma (sample 1B), caused further partial argon loss from the biotite in 1C.

Nevertheless, despite these uncertainties of detailed interpretation, it would appear that the Pimampiro intrusion (if it exists as a single entity) was probably emplaced in late Cretaceous times.

3.2 Chingual orthogneiss

This has given an Rb/Sr age of 156 ± 21 Ma, with a low initial ratio, which was interpreted as recording emplacement in mid-Jurassic times. In the present study three samples of biotite separated from the same samples used in the Rb-Sr whole-rock isochron, have significantly different potassium contents yet have given identical K-Ar apparent ages. The mean age of 19 ± 1 Ma is interpreted as reflecting a significant reheating event in this area in early Miocene times.

3.3 Sacha orthogneiss

Because of inaccessibility and poor exposure only one sample, from a loose boulder in a stream, was collected from this rock body. This was identified in the field as a variably foliated, medium-grained, biotite + hornblende tonalite. Other similar boulders in the area contained abundant mafic xenoliths. The field geologists were of the opinion that this could be related to the Chingual 'gneiss', despite the fact that no amphibole was seen in the latter. The biotite and hornblende from this rock record significantly different ages, and both are substantially older than the K-Ar results for Chingual; though considerably less than the Rb-Sr age. This could be the result of partial overprinting during the ca. 20 Ma event recorded at Chingual but gives little indication of the original age of the Sacha rock or its relationship to Chingual.

3.4 Papallacta amphibolite dyke

Extremely limited exposure meant that it was only feasible to collect one sample of this dyke. The hornblende appeared relatively fresh in hand specimen (but this should be confirmed by petrographic analysis) and yielded a reasonably pure and homogeneous mineral separate for analysis. The apparent age of 367 ± 5 Ma is the oldest found in this study and, if correct, implies that the greenschists cut by this dyke are the oldest basement material found in the Cordillera Real. Nevertheless, there is always a possibility of excess argon contamination, particularly in low-K samples, which would make the age spuriously old, and it is obviously unwise to rely on data from a single sample. It is considered essential that further similar dykes and samples from the basement material, be analysed before these rocks can confidently be identified as pre-Carboniferous.

3.5 Abitagua granite

All the mafic minerals in this intrusion appeared rather altered in hand specimen and many of the biotites had a greenish tinge suggesting extensive chloritisation. Consequently, mineral separation proved very difficult because both biotite and amphibole concentrates had a wide range of densities and magnetic susceptibilities. This is particularly reflected in the low K-contents for what had been identified as biotite. The results for all the samples from the northern outcrop, and a very low-K 'biotite' from the south, yield K-Ar apparent ages which are significantly less than the Rb-Sr isochron age for this intrusion (162 ± 1 Ma) and clearly show the effect of argon loss due to this alteration. It is unlikely that these samples would have been chosen for K-Ar dating if a petrological description had been available to assist in selection.

Only two samples give apparently useful ages. Hornblende from granite sample 6A has given a mean age of 158 ± 6 Ma (indistinguishable from the Rb-Sr age), whilst that from a cross-cutting andesitic dyke (sample 7) has yielded an apparently older result of 171 ± 6 Ma. Nevertheless, it must be noted that although the 2-sigma error bars for these results do not overlap, these errors are the computed standard error on the mean - which may not be realistic when only duplicate determinations are involved. If the individual analytical precision estimates are used then these results are not significantly different at the 95% confidence level and perhaps the best representation of the estimate of the age is around 160-170 Ma. This is in reasonable agreement with a single K-Ar age on biotite quoted by Hebert and Pichler (1983; 178 Ma) and with that from hornblende from a boulder found in the Rio Zúñag (AD.ML5; 169 ± 6 Ma) reported in the earlier pilot K-Ar study. Thus, the most reliable K-Ar dates are concordant with the Rb-Sr and together these results strongly suggest emplacement of the Abitagua granite batholith in mid-Jurassic times.

3.6 Azafrán pluton

Although this pluton was assumed to be older than Abitagua because of its foliated appearance, the Rb-Sr isochron age, reported previously, was significantly younger, at 120 ± 5 Ma (cf. 162 Ma for Abitagua). Similarly, the K-Ar age for biotite, on both an altered specimen from a normal granite sample (8E) and a fresh, high-K specimen from a cross-cutting biotite-rich vein (9), is significantly younger than that for Abitagua. Moreover, at 49 ± 3 Ma, this K-Ar age is considerably younger than the Rb-Sr age for Azafrán and is presumably reflecting a later thermal event - though this is not recorded in any of the adjacent Abitagua samples. It may be significant that the youngest K-Ar age recorded in the Abitagua samples is slightly older, but within error, of the Rb-Sr age for Azafrán and this may suggest that the subsequent emplacement of Azafrán was responsible for the loss of argon from some of the Abitagua samples.

3.7 Río Verde granodiorite

This was thought by the field geologists to be related to either the Azafrán or the Abitagua intrusions. The earlier Rb-Sr investigation did not help in resolving this uncertainty since the samples have very low, and similar, Rb/Sr ratios and lie at the low end of both the granite isochrons. Two very similar samples of remarkably fresh hornblende + biotite tonalite/diorite (field identification) were collected from a 30-meter riverside exposure, on either side of what appeared to be a large raft of schistose country rock. Both samples yielded apparently fresh specimens of biotite and hornblende (this should be confirmed petrographically) but although in both cases the K-Ar ages are concordant for the co-existing minerals, the mean ages for each specimen are very different from one another.

Sample 10A, from the northern side of the exposure, has given an age of 128 ± 5 Ma, which is very similar to the Rb-Sr age for Azafrán, whereas sample 10B, from the southern side, nearer to the Azafrán outcrop, gave 174 ± 3 Ma - similar to Abitagua (and similar to the K-Ar age of 171 ± 5 Ma for sample AD.ML4, from a boulder in the Rio Verde, reported previously).

Since these ages are defined by co-existing, relatively unaltered mineral pairs it must be concluded that they are recording real geological events. In view of the close proximity of the two collecting sites, it is inconceivable that 10B would have been unaffected by the ca. 128 Ma event recorded in 10A if they had been so close at the time, and thus it is concluded that the zone of schistose rock must represent a major shear which subsequently brought the two samples close to one another. It is suggested that further samples be collected from this schist zone in order to determine the age of shearing - which could be the cause of the ca. 50 Ma K-Ar ages recorded in the Azafrán biotites. Thus, the Rio Verde intrusion does not appear to be a single entity and the isotopic data suggest that it may contain components related to both of the major plutons. A petrological and full geochemical investigation may possibly substantiate this conclusion.

3.8 Agoyán garnet-gneiss

Three samples of white mica, identified in hand specimen as muscovite, were separated from this rock, but it was noted that they were not typical and all had a greenish-grey appearance. The potassium values clearly demonstrate that these minerals were mis-identified and suggest that they are more likely to be the sodium rich variety, paragonite - but this needs to be confirmed. Because of their low K-content these samples produced relatively small amounts of radiogenic argon. Hence the percent of atmospheric contamination was high and this caused an increase in the error on the calculated age. Nevertheless, the ages all agree within analytical error and have a mean of 76 ± 3 Ma. This compares favourably with published ages in the range 54 to 79 Ma, some on undisputed high-K muscovites, and suggests that these low-K micas may also be reliable geochronometers.

It is clear that a widespread pervasive thermal event affected the rocks in this area in late Cretaceous times and the simple interpretation is that this represents the main gneissification. The age of 417 Ma reported by Evernden (1961) for garnet gneiss from Agoyán cannot be confirmed.

In the course of this study garnets were also separated from these rocks for Sm-Nd dating. Unfortunately, time was not available during Phase 1 of this project for these analyses to be made. It must be noted, however, that it is likely that the garnets crystallised at the same time as the micas (again this may be confirmed by petrographic analysis) and can be expected to be recording the same age. If this is so then it is unlikely that Sm-Nd analysis will yield any useful results since the age is too young to be suitable for this method. Only if the original age of the garnets is considerably older (say >300 Ma), and the mica ages are reflecting a relatively mild event which did not affect the Sm-Nd systematics, will this approach be appropriate.

3.9 Pungalá granodiorite

The hornblende and biotite in samples 12A and 12B were highly altered and difficult to separate so only the mafic concentrate was analysed. Nevertheless, the results are in good agreement with those from the relatively fresh biotite and hornblende separates from sample 12C which have themselves given identical ages. According to the field geologist the intrusion is relatively unaltered and unfoliated. It is surrounded by young volcanics and is thought to be relatively young. Consequently, it is suggested that the mean age of 43 ± 2 Ma is reflecting a major isotopic event which is probably recording the time of emplacement of this rock in Eocene times.

3.10 Magtayán granodiorite

Despite a four-hour drive along virtually impassable dirt tracks no in-situ outcrop of this rock was found. Consequently, three samples were taken from widely separated boulders sticking up out of the peat. Since the collecting sites were in an intermontane basin it was assumed that the boulders came from distant, but inaccessible cliffs which were reputed to be the outcrop of this intrusion. Samples 13A and 13C were rather similar medium-grained hornblende + biotite granodiorite (but very little biotite in 13C) but 13B was a much coarser, hornblende-rich variety, with no obvious biotite.

The biotite from sample 13A has given an age which is significantly younger than those for the hornblendes in 13B and 13C, but it must be noted that this has a relatively low K-content and is presumably highly altered (should be confirmed by thin section). The hornblende in this sample also appears to be slightly younger, but this may also be due to alteration. Nevertheless, the results are not very different from one another and it is likely that this intrusion was emplaced around 75-80 Ma ago, in the late Cretaceous.

3.11 Peggy Mine blue quartz granite

Three samples of this rock have given a poor Rb-Sr whole-rock 'errorchron' age of 82 ± 28 Ma with a high initial strontium ratio implying resetting or derivation from pre-existing crustal material. In the present study relatively fresh (high K-content) biotite was separated from two of these samples and dated by K-Ar. The results are in good agreement, with a mean of 84 ± 2 Ma and identical (within error) with the Rb-Sr result. This again suggests a major event in the late Cretaceous and it is noteworthy that this intrusion lies along strike from the Magtayán samples, above.

3.12 Paute volcanics

These rocks are presumed to have originally been andesitic lavas but are now very altered. They are thought to be part of one of the oldest Formations in the area. Two samples were collected from very poor exposures and mafic phenocrysts were separated for analysis. These were identified in the field as hornblende but sample 15B in particular has a very low K-content and is most probably actinolite (this should be confirmed). The two samples had high proportions of atmospheric argon contamination (due to low K-content) and consequently there are high errors on the calculated ages. The two ages agree with one another within analytical error (108 ± 8 Ma for 15A and 142 ± 36 Ma for 15B), but it is likely that they reflect partial overprinting during the late Cretaceous event rather than the original age of these rocks.

3.13 Zamora batholith

The Rb-Sr data for these rocks was very scattered and indicated severe disturbance of the isotopic systems. Nevertheless, there were strong indications of a late-stage event associated with felsite veining at around 180 Ma (early Jurassic) and suggestions of an original age of around 240 Ma (early Triassic). The K-Ar data for these samples is equally enigmatic. Mineral separation was particularly difficult and the low K-contents suggest that many of the separated minerals are highly altered and/or mixtures of different species (again this requires petrographic confirmation and possible identification of the least altered samples). Moreover, because of paucity of exposure, in several cases loose boulders or individual isolated outcrops were sampled - on the assumption that all the rocks in the area were related in some way to the main batholith and would help to constrain its age.

In some instances, this assumption does not appear to have been well founded. In particular sample 20, from an isolated exposure, and sample 22F, from a loose boulder in a stream, are significantly younger than the majority and possibly represent later events at ca. 125 Ma and 20-30 Ma respectively. Sample 16C was highly epidotised and has also given a young age, though with a very high error. All the other samples analysed fall in the range 153 ± 12 Ma (mid Jurassic) to 222 ± 13 Ma (late Triassic); which would appear to be in broad agreement with the Rb-Sr data.

Nevertheless, it is noteworthy that two hornblende - biotite pairs from the north-eastern outcrop (21A and 21G) give highly concordant ages with a mean of 154 ± 4 Ma, and this is also recorded in hornblende FV.60 (151 ± 5 Ma) from the earlier study. It is considered that this age is reflecting a significant isotopic event which was presumably an episode of re-heating or hydrothermal activity which reset the isotopic systems, rather than initial emplacement of the batholith.

Two other samples, reputedly from the Zamora batholith, were dated in the earlier study and yielded K-Ar ages for biotites of 83 ± 2 Ma and 97 ± 3 Ma. These are considered to be the result of later partial argon loss. Furthermore, only one sample has given an age in excess of 200 Ma. This is hornblende separated from sample 18 which is from a loose porphyritic andesite block in a small river and was thought by the field geologist to represent an early volcanic carapace to the main batholith. Although the agreement between this result and some of the Rb-Sr data may appear to lend credence to this suggestion it is considered unwise to place too much reliance on a single K-Ar date and it is strongly suggested that further samples of this 'early volcanic phase' (preferably from in-situ outcrop) should be analysed in order to substantiate this age.

3.14 Sabanilla migmatite

This rock was originally described as a metasomatic granite. Eight samples from a variety of phases gave rather scattered Rb-Sr results (documented in the earlier report) but suggested an age of around 230-240 Ma; similar to the nearby Zamora batholith. Three very fresh samples of biotite were separated from these samples and analysed for K-Ar. They all give identical ages with a mean of 82 ± 2 Ma. This is unlike any of the results from Zamora, but similar to those obtained for Peggy Mine, Paute, and Magtayán, all of which lie roughly along strike but further to the north. These ages may therefore indicate a southerly extension of the zone of late Cretaceous activity.

3.15 Valladolid basement complex

A wide area of poorly exposed, highly altered and complex structured gneissose material is cut by a variety of late veins and dykes. A few of these were exposed in road cuttings and appeared to contain relatively fresh amphiboles and micas, so they were collected in an attempt to place some constraint on the minimum age of the basement rocks. Sample 24A was an amphibolite dyke containing biotite and hornblende. The two minerals have given discordant ages with the hornblende (132 ± 5 Ma) significantly older than the biotite (76 ± 3 Ma). The other three samples were from quartz-mica pegmatite veins. Samples 24B (biotite) and 24D (muscovite) have given almost identical ages of 77 ± 3 Ma and 72 ± 2 Ma respectively (concordant with the biotite in 24A), whilst the coarse muscovite in sample 24C is apparently slightly younger at 65 ± 2 Ma.

These data may be taken to indicate a significant isotopic event at ca. 70-75 Ma (late Cretaceous); the younger age for the coarse mica probably being attributable to poor retentivity in this specimen. The age of ca. 130 Ma recorded in the hornblende is probably the result of partial overprinting at this time but nevertheless suggests that the rocks of the basement complex could be as young as late Jurassic.

3.16 Río Mayo pluton

In the previous Rb-Sr study five specimens of medium-grained tonalitic-to-dioritic material which appeared to be the earliest phase in a rather complex sequence of magmatic events (see earlier report) gave a poorly constrained age of 144 ± 35 Ma. In the present study hornblende from a cross-cutting porphyry dyke has given an age of 143 ± 7 Ma, which presumably sets a minimum for this intrusion. Three samples from the main phase of the pluton, however, have given apparently reliable, concordant ages for co-existing hornblende-biotite pairs which have an overall mean of 179 ± 5 Ma and are most probably reflecting the age of emplacement of this rock in early to mid Jurassic times.

3.17 Portachuela pluton

Seven samples of highly variable rock type from separate exposures along a new road cutting were analysed for Rb-Sr. Because of the poor exposure and lack of previous detailed mapping or petrographic study it is not certain whether these represent different phases of a single magmatic event or completely separate intrusions. Six of these samples had very similar Rb-Sr ratios and gave a cloud of points on the isochron diagram from which no age could be calculated. One sample (27F) had a much higher Rb-Sr ratio and when this was included the calculated age was 33 ± 11 Ma (MSWD=96).

Four of these samples were selected for mineral separation and K-Ar analysis. Co-existing hornblende and biotite from 27F gave concordant ages with a mean of 22 ± 5 Ma, and minerals from two other samples are not significantly different from this. The overall mean of 20 ± 2 Ma is probably a good estimate of the age of this (these) intrusion(s) and this, together with the Rb-Sr age, suggests emplacement in early Miocene times. Only sample 27A, from the extreme end of the traverse, has given a significantly different age, at 12 ± 1 Ma. This sample is unusual in that it is a fine grained, porphyritic, sub-volcanic facies, and it was noted in the field that this may not be part of the same pluton. The biotite separated from it appears relatively fresh in hand specimen and this is borne out by the relatively high K-content. Thus, it is likely that this age is reliable and indicates a significantly later age of emplacement for this rock.

3.18 Catamayo pluton

Two samples of extremely fresh biotite were separated from this late, post-tectonic, biotite-rich granitoid, and both have given almost identical ages with a mean of 58 ± 2 Ma. This is taken to indicate emplacement of this pluton in Palaeocene times.

4. Conclusions

It is clear that the Cordillera Real area has been subjected to a complex succession of magmatic and tectonic events throughout most of Mesozoic and Cenozoic times, and evidence for many of the earlier events has been almost obliterated by subsequent activity. A histogram of the latest K-Ar data obtained in the NIGC laboratory, reported here and in BGS Isotope Geology Unit Report 87/5, demonstrates that, apart from a brief hiatus in the early Cretaceous, there is a continuous spectrum of apparent ages from ca. 200 Ma to ca. 10 Ma ago. It is considered likely that most of these ages reflect real isotopic events rather than partial overprinting. There is some indication in the data of ages older than 200 Ma but these are based on single sample analyses and need to be substantiated before any firm conclusions can be drawn about the extent and importance of any pre-Jurassic precursors.

In particular, the age of ca. 370 Ma recorded in a single hornblende sample from Papallacta (not depicted on the histogram) is by far the oldest age determined in this study and (apart from the suspect result of 417 Ma reported by Evernden for the Agoyán gneiss, and the equally suspect age of 743 Ma for an amphibole with 0.084%K reported by Kennerley) the oldest result so far obtained by any method for any rock in Ecuador. It is obviously essential that further field investigations be carried out and further samples be analysed from this area (preferably utilising additional dating techniques) before a pre-Carboniferous component can be confidently identified.

C. C. Rundle
November 1988

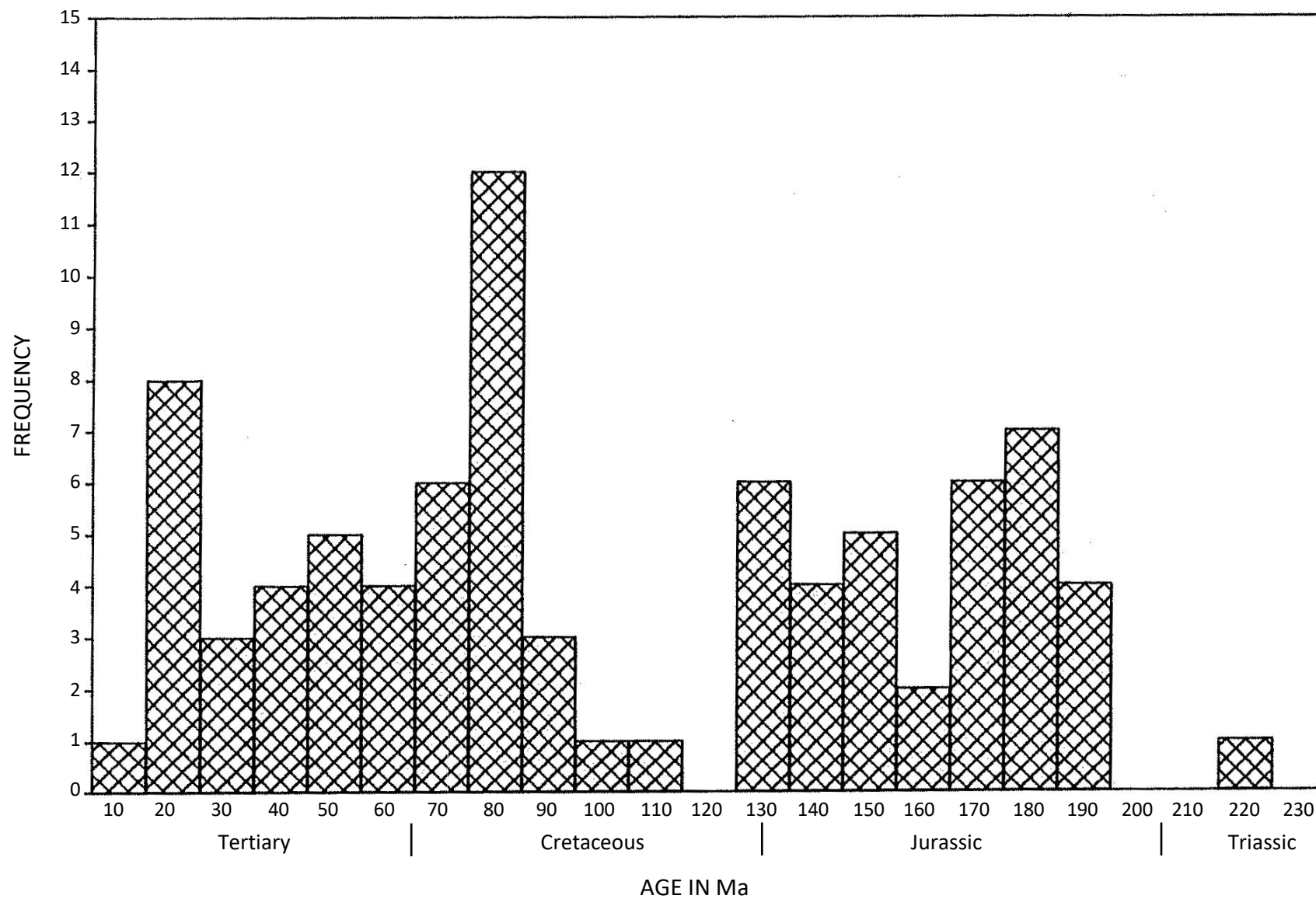


Figure 1. Potassium-Argon ages from the Cordillera Real, Ecuador

Table 1. K-Ar results for the Cordillera Real Project, Ecuador

(NB: Hb = hornblende; Bi = biotite; Mosc = muscovite)

Zone	Sample No.	%K $\pm$ %sd	Atmos. ⁴⁰ Ar (%)	Rad. ⁴⁰ Ar $\pm$ % sd (nl/g)	Age $\pm$ 2sd (Ma)
Pimampiro	1A Hb	0.363 $\pm$ 1.0	59.8	1.172 $\pm$ 1.9	81 $\pm$ 3
			77.8	1.142 $\pm$ 3.8	79 $\pm$ 6
	1A Bi	4.27 $\pm$ 1.0	46.9	14.18 $\pm$ 1.3	84 $\pm$ 3
	1B Mosc	8.58 $\pm$ 1.0	41.9	18.06 $\pm$ 1.3	53 $\pm$ 2
			60.5	15.95 $\pm$ 2.4	47 $\pm$ 2
	1C Hb	0.371 $\pm$ 1.0	54.4	1.341 $\pm$ 1.6	91 $\pm$ 3
			62.3	1.389 $\pm$ 2.0	94 $\pm$ 4
	1C Bi	4.72 $\pm$ 1.0	21.6	13.71 $\pm$ 1.1	73 $\pm$ 2
Chingual			58.2	13.73 $\pm$ 2.2	73 $\pm$ 4
	2C Bi	6.95 $\pm$ 1.5	64.5	5.399 $\pm$ 2.3	20 $\pm$ 1
	2E Bi (dense)	7.81 $\pm$ 1.0	54.1	5.672 $\pm$ 1.6	19 $\pm$ 1
Sacha	2E Bi(light)	6.41 $\pm$ 1.0	69.1	4.821 $\pm$ 3.1	19 $\pm$ 1
	3 Hb	0.679 $\pm$ 4.7	73.4	0.904 $\pm$ 3.1	34 $\pm$ 4
			63.8	0.816 $\pm$ 2.3	31 $\pm$ 3
	3 Bi	6.629 $\pm$ 1.5	60.4	6.536 $\pm$ 1.8	25 $\pm$ 1
Papallacta			41.8	6.392 $\pm$ 1.3	25 $\pm$ 1
	4 Hb	0.612 $\pm$ 1.0	19.3	9.563 $\pm$ 1.0	363 $\pm$ 9
Abitagua (North)			39.0	9.794 $\pm$ 1.2	371 $\pm$ 10
	5G Hb	0.849 $\pm$ 2.0	58.9	4.638 $\pm$ 2.4	135 $\pm$ 8
	5G Mafics?	1.455 $\pm$ 1.0	40.5	8.078 $\pm$ 1.6	137 $\pm$ 5
Abitagua (South)	5G Bi?	1.860 $\pm$ 3.0	31.5	11.05 $\pm$ 1.1	147 $\pm$ 9
	6A Bi?	0.537 $\pm$ 1.0	73.1	2.724 $\pm$ 4.7	126 $\pm$ 12
			77.1	2.776 $\pm$ 3.6	128 $\pm$ 9
	6A Hb	0.569 $\pm$ 1.5	56.6	3.512 $\pm$ 1.9	152 $\pm$ 7
			65.3	3.806 $\pm$ 2.8	164 $\pm$ 10
	7 Hb	0.323 $\pm$ 1.6	57.8	2.206 $\pm$ 2.0	168 $\pm$ 8
Azafrán			59.8	2.298 $\pm$ 1.9	174 $\pm$ 8
	8E Bi?	2.540 $\pm$ 1.0	57.5	4.706 $\pm$ 1.7	47 $\pm$ 2
	9 Bi	5.914 $\pm$ 1.0	37.2	11.79 $\pm$ 1.9	51 $\pm$ 2
Río Verde			50.3	11.38 $\pm$ 1.5	49 $\pm$ 2
	10A Hb	0.995 $\pm$ 1.0	64.9	5.145 $\pm$ 2.6	128 $\pm$ 7
	10A Bi	5.02 $\pm$ 1.0	27.9	25.96 $\pm$ 1.2	128 $\pm$ 4
	10B Hb	0.827 $\pm$ 1.0	40.0	5.777 $\pm$ 1.3	171 $\pm$ 5
Agoyán	10B Bi	5.296 $\pm$ 1.2	14.5	38.02 $\pm$ 1.1	176 $\pm$ 5
	11B Mica	0.135 $\pm$ 3.0	95.3	0.421 $\pm$ 21.3	78 $\pm$ 33
	11D Mica	0.156 $\pm$ 4.5	94.6	0.457 $\pm$ 18.2	74 $\pm$ 27
Pungalá	11E Mica	0.472 $\pm$ 2.5	79.1	1.413 $\pm$ 4.1	75 $\pm$ 7
	12A Hb + Bi	0.264 $\pm$ 3.2	76.3	0.471 $\pm$ 3.6	45 $\pm$ 4
	12B Hb + Bi	1.969 $\pm$ 1.3	51.9	3.276 $\pm$ 1.5	42 $\pm$ 2
	12C Hb	1.25 $\pm$ 1.0	53.2	2.080 $\pm$ 1.5	42 $\pm$ 2
Magtayán	12C Bi	5.07 $\pm$ 1.0	38.2	8.298 $\pm$ 1.2	42 $\pm$ 1
	13A Hb	1.04 $\pm$ 1.0	51.2	3.066 $\pm$ 1.5	74 $\pm$ 3
	13A Bi	4.08 $\pm$ 1.0	76.8	10.95 $\pm$ 3.6	68 $\pm$ 5
	13B Hb	0.409 $\pm$ 1.0	60.1	1.397 $\pm$ 2.6	86 $\pm$ 5
			63.5	1.446 $\pm$ 2.1	89 $\pm$ 4
	13C Hb	0.996 $\pm$ 1.0	47.3	3.139 $\pm$ 1.4	79 $\pm$ 3

Table 2. K-Ar results for the Cordillera Real Project, Ecuador

Zone	Sample No.	%K $\pm$ %sd	Atmos.40 Ar (%)	Rad. 40 Ar $\pm$ % sd (nl/g)	Age $\pm$ 2sd (Ma)
Peggy Mine	14A Bi	6.03 $\pm$ 1.0	41.6	19.5 $\pm$ 1.3	81 $\pm$ 3
	14D Bi	6.10 $\pm$ 1.5	55.0	20.83 $\pm$ 1.9	86 $\pm$ 4
Paute	15A Hb	0.12 $\pm$ 1.0	81.6	0.474 $\pm$ 4.8	99 $\pm$ 10
	15B Hb?	0.063 $\pm$ 1.7	76.4	0.554 $\pm$ 5.2	115 $\pm$ 12
Napurca (Zamora, North-west)	16C Hb	0.371 $\pm$ 1.0	92.1	0.361 $\pm$ 13.0	142 $\pm$ 36
	16H Hb	0.289 $\pm$ 1.0	88.5	2.009 $\pm$ 8.1	134 $\pm$ 21
	17 Hb	0.227 $\pm$ 2.4	71.8	2.107 $\pm$ 2.8	178 $\pm$ 10
	18 Hb	0.168 $\pm$ 1.0	40.6	1.776 $\pm$ 1.5	191 $\pm$ 10
	19 Hb	0.205 $\pm$ 1.0	71.9	1.602 $\pm$ 3.1	230 $\pm$ 14
	20 Hb	0.591 $\pm$ 1.0	84.3	1.487 $\pm$ 5.6	214 $\pm$ 23
	20 Bi?	2.34 $\pm$ 1.0	50.2	1.581 $\pm$ 1.5	188 $\pm$ 6
			40.1	4.356 $\pm$ 1.2	126 $\pm$ 4
			18.5	4.398 $\pm$ 1.0	127 $\pm$ 4
			37.3	15.77 $\pm$ 1.2	166 $\pm$ 5
Zamora (North- east)	21A Hb	0.99 $\pm$ 2.8	38.0	16.35 $\pm$ 1.2	171 $\pm$ 5
	21A Bi	3.93 $\pm$ 1.0	64.0	6.134 $\pm$ 2.2	153 $\pm$ 10
	21G Hb	0.971 $\pm$ 4.0	25.7	24.32 $\pm$ 1.1	153 $\pm$ 4
	21G Bi	5.16 $\pm$ 1.0	45.6	6.036 $\pm$ 1.3	153 $\pm$ 12
Río Pituca (Zamora South)	22B Bi	4.70 $\pm$ 1.0	20.8	34.20 $\pm$ 1.1	178 $\pm$ 5
	22E Hb	0.32 $\pm$ 2.0	64.2	2.363 $\pm$ 3.3	181 $\pm$ 14
	22F Hb	0.493 $\pm$ 1.3	89.0	0.648 $\pm$ 12.5	34 $\pm$ 8
Sabanilla	23D Bi	7.81 $\pm$ 1.0	25.7	25.44 $\pm$ 1.2	82 $\pm$ 3
	23E Bi	7.64 $\pm$ 1.0	22.9	24.93 $\pm$ 1.2	82 $\pm$ 3
	23F Bi	7.58 $\pm$ 1.0	31.3	24.69 $\pm$ 1.2	82 $\pm$ 3
Valladolid	24A Hb	0.584 $\pm$ 1.2	64.6	3.012 $\pm$ 2.1	128 $\pm$ 6
	24A Bi	5.38 $\pm$ 1.5	71.4	3.178 $\pm$ 2.8	135 $\pm$ 8
	24B Mosc	8.36 $\pm$ 1.0	40.8	16.30 $\pm$ 1.2	76 $\pm$ 3
	24C Mosc	7.39 $\pm$ 1.0	54.8	22.48 $\pm$ 1.6	77 $\pm$ 3
	24D Bi	7.09 $\pm$ 1.0	51.4	21.60 $\pm$ 1.5	65 $\pm$ 2
	24D Bi	7.09 $\pm$ 1.0	12.6	20.35 $\pm$ 1.0	72 $\pm$ 2
Río Mayo	25 Hb	0.382 $\pm$ 2.2	34.7	2.208 $\pm$ 1.3	143 $\pm$ 7
	26B Hb	0.499 $\pm$ 1.0	78.8	3.562 $\pm$ 3.9	175 $\pm$ 14
	26B Bi	4.19 $\pm$ 1.0	24.1	29.34 $\pm$ 1.1	172 $\pm$ 5
	26C Hb	0.549 $\pm$ 1.0	78.6	4.172 $\pm$ 3.9	186 $\pm$ 14
	26C Bi	5.21 $\pm$ 1.2	38.7	39.87 $\pm$ 1.2	187 $\pm$ 6
	26E Hb	0.375 $\pm$ 1.0	78.0	2.688 $\pm$ 3.8	176 $\pm$ 13
	26E Bi	2.13 $\pm$ 1.0	34.1	15.53 $\pm$ 1.1	178 $\pm$ 5
Portachuela	27A Bi	6.56 $\pm$ 1.0	81.2	3.109 $\pm$ 4.5	12 $\pm$ 1
	27C Hb	0.839 $\pm$ 1.0	67.3	3.101 $\pm$ 2.3	12 $\pm$ 1
	27C Bi	6.21 $\pm$ 1.0	94.3	0.670 $\pm$ 17.2	20 $\pm$ 7
	27F Hb	0.508 $\pm$ 1.0	77.7	4.055 $\pm$ 3.7	17 $\pm$ 1
	27F Bi	6.38 $\pm$ 1.0	90.9	0.469 $\pm$ 10.9	24 $\pm$ 5
	27G Bi	6.94 $\pm$ 1.0	67.2	4.645 $\pm$ 2.3	19 $\pm$ 1
	27G Bi	6.94 $\pm$ 1.0	61.4	4.893 $\pm$ 2.5	18 $\pm$ 1
Catamayo	29A Bi	7.18 $\pm$ 1.0	13.7	16.08 $\pm$ 1.0	57 $\pm$ 2
	29B Bi	7.62 $\pm$ 1.0	36.9	17.57 $\pm$ 1.2	58 $\pm$ 2

APPENDIX 9

Palaeontological reports

BRITISH GEOLOGICAL SURVEY
Natural Environment Research Council

TECHNICAL REPORTS
Stratigraphy Series

Biostratigraphy Research Group Report

Keyworth, Nottinghamshire British Geological Survey

Palynological analysis of samples from Ecuador

Report WH/88/320R - PD 88/288

Geographical index

Ecuador

Subject index

Palynology, Ecuador

Distribution:

Keyworth: Dr. J. D. Bennett, Overseas Division
Dr. B. Owens, Biostratigraphy Research Group

Overseas: Dr. J. Aspden.

Samples submitted by : J. Aspden
Samples prepared by : R. U. Leader
Samples examined by : S. G. Molyneux

This report deals with eleven samples submitted from Ecuador.

MPA 27704 (ex CR-FV-87-336). Coordinates 2312-0159.

Locality: Tignas. Cleaved semi-pelites from Loja Pelite. The sample proved to be barren.

MPA 27705 (ex CR-FV-87-339) Coordinates 2682-0065.

Locality: Moradillas. Cleaved semi-pelites from Loja Pelite. The sample yielded opaque fragments of probable organic origin, but no recognisable microfossils.

MPA 27706 (ex CR-FV-87-352) Coordinates 4885-7586.

Locality: Piedra Liza. Mudstone with leaf impressions. The sample proved to be barren.

MPA 27707-27714 (ex RB-87-251A-H)

The remaining samples are all from the Guamote division, at Punín, south of Riobamba (co-ordinates 7614-98049). All the samples yielded opaque fragments of probable organic origin, but no microfossils were seen.

Conclusions

The absence of any identifiable microfossils means that none of the samples can be dated palynologically.

S. G. Molyneux

24 October 1988

**Palynological analysis of samples from
the Maguazo Division, Río Jadán, Ecuador**

Report WH/88/341R - PD 88/307

Geographical index

Ecuador

Subject index

Palynology, Ecuador,

Acritarchs, Spores,

Ordovician, Mesozoic

Distribution:

Keyworth: Dr. J. D. Bennett

Dr. B. Owens

Dr. J. B Riding

Overseas: Dr. J. Aspden

Samples submitted by : J. Aspden

Samples prepared by : R. U. Leader

Samples examined by : S. G. Molyneux

Two samples from the Maguazo Division, Río Jadán, have been analysed for palynomorphs.

MPA 28366 (ex CR-FV-87-359B). Coordinates 3921-8419. This sample, of ribbon chert, yielded opaque fragments of possible organic origin, but no microfossils were seen.

MPA 28367 (ex CR-FV-87-359A) Coordinates 3921-8419.

Calcareous black phyllite with chert. The sample yielded a sparse mixture of dark brown acritarchs and paler, clear or yellow spores. The acritarchs are poorly preserved, and hence determinations are difficult, but they include forms referred to *Cymatiogalea*, *Acanthodiacrodium* and *Polygonium*. These genera suggest that the acritarchs are of early Ordovician age. The spores resemble Mesozoic taxa, and have been passed to Dr. J. B. Riding for identification. Confirmation of a Mesozoic age would imply that the acritarchs are reworked.

S. G. Molyneux

4 November 1988

**Palynological analysis of samples from the Palenque cherts,
Río Palenque, Ecuador.**

Report WH/88/342R - PD 88/308

Geographical index
Ecuador

Subject index
Palynology, Ecuador,

Distribution:

Keyworth: Dr. J. D. Bennett
Dr. B. Owens

Overseas: Dr. J. Aspden

Samples submitted by : J. Aspden
Samples prepared by : R. U. Leader
Samples examined by : S. G. Molyneux

Eight samples of chert from the R. Palenque were analysed for palynomorphs. All proved to be barren.

MPA 28368-28375. Santa Rosa 1:100000 sheet.
Coordinates 3°25'5"/79°45' W. About 50 metres upstream from Palenque village.

S. G. Molyneux
4 November 1988

**A palynological investigation of a sample from the Maguazo Division,
Río Jadán, Ecuador**

Report WH/88/347R - PD/88/311

Geographical index

Ecuador

Subject index

Palynomorphs, Biostratigraphy

Jurassic, Ordovician

Copies to: 1. J. A. Aspden (Overseas)
2. J. D. Bennett
3. S. G. Molyneux
4, 5. Biostratigraphy Research Group Files

Samples submitted by : J. Aspden
Samples prepared by : R. U. Leader
Samples examined by : J. B. Riding

1. Introduction

A sample from the Maguazo Division of Río Jadán, Ecuador was submitted for palynological analysis in order to attempt a detailed age assessment. The lithology is calcareous black phyllite with chert; the sample was numbered CR-FV-359A (coordinates 3921-8419) and registered as MPA-28367.

S. G. Molyneux identified poorly-preserved early Ordovician acritarchs and Mesozoic miospores (see WH/88/341R). The purpose of this report is the identification of the Mesozoic palynomorphs and elucidation of their biostratigraphical significance.

2. Palynostratigraphy

The sample contains, in addition to the early Ordovician acritarchs, numerous pollen grains with subordinate spores, dinoflagellate cysts and miscellaneous microplankton. Appendix 1 lists the entire Mesozoic palynoflora. The dinoflagellate cyst florule includes *Gonyaulacysta jurassica* and *Tubotuberella eisenackii*. The latter taxon is confined to the Callovian and Oxfordian stages (Jurassic). The remainder of the species are indicative of the mid/late Jurassic and, as such, are consistent with a Callovian to Oxfordian age.

3. Summary

MPA-28367 is Callovian to Oxfordian in age on the basis of dinoflagellate cyst evidence. Significant numbers of early Oxfordian acritarchs have been reworked into the sampled horizon.

Table 1. List of Mesozoic Taxa

Polen grains

bisaccate polen– undifferentiated
Callialasporites dampieri
Callialasporites segmentatus
Callialasporites turbatus
Cerebropollenites macroverrucosus
Classopollis meyeriana
Cycadopites spp.
Perinopollenites elatoides

Spores

Cyathidites australis
Cyathidites sp.

Dinoflagellate cysts

Gonyaulacoide dinoflagellate cysts – indeterminate
Gonyaulacysta jurassica
Sentusidinium sp.
Tubotuberella eisenackii

Miscellaneous microplankton

Tasmanites sp.
Micrhystridium sp.

J. B. Riding

14 November 1988

**Cretaceous ammonites from the province of
Zamora Chinchipe in SE Ecuador**

Report WH/88/416R - PD/88/377

Geographical index

Ecuador

Subject index

Ammonites, Cretaceous

Dr. J. D. Bennett

Dr. J. A. Aspden

Dr. B. Owens

File: Ecuador

Material

ER1 Dark shale with ammonites, three specimens; from the headwaters of the Río Nangaritza.

CR-FV-842B Pale grey calcilutite with indeterminate shell fragments, some fissures/borings infilled with coarser calcarenite.

CR-FV-842C Dark grey black shale, calcareous and somewhat silty, with ammonites; from the Río Vergel (float).

The ammonite bearing material of ER1 and CR-FV-842C was sent to Dr. M. K. Howarth (British Museum, Natural History) for determination. Dr. Howarth's conclusions were independently supported by Dr. H. G. Owen of the same institution.

Dr Howarth's identifications were:

ER-1A y ER-1B Poorly preserved Mojsisoviciinae.

ER-1C Oxytropidoceras sp. (fine ribbed specimen), Adkinsites sp. (coarse ribbed specimen on opposite side).

CR-FV-842C Oxytropidoceras sp., Adkinsites sp., Brancoceras sp.

He further commented: "All the specimens belong to the Middle Albian Subfamily Mojsisoviciinae of which the best-known genus is Oxytropidoceras. None of them are determinable to species but the small finely-ribbed specimen on one side of Er.1C is very distinctive and there can be no doubt this is the right age and the right group of ammonites. Hugh Owen arrived independently at the same conclusion. Similar ammonites occur widely in Peru, Ecuador, Venezuela and Colombia, and one of the genera is called Venezoliceras. Many years ago, I saw ammonites like these in the basal part of the Cazaderos Formation in Ecuador".

H. C. Ivimey-Cook (from determinations by Dr. M. K. Howarth)
14 December 1988

Conodont investigation of 10 BGS samples from Ecuador

Report WH/89/13R - PD 89/13

Geographical index

Ecuador

Subject index

Pre-Jurassic, Microfauna

BGS Report No. 3

December de 1988

Micropalaeontology Unit

Department of Geology

Nottingham University

- **CR-FV-473. Block 1.**

Lithology: Light-medium grey fine muddy micrite.

Sample weight: 1283 g.

Conodont elements recovered: None.

Other microfossils: Fairly common but poorly preserved fish remains, including dermal denticles and plates, scales and teeth.

Remarks: Post-burial effects have resulted in the fish remains being albid, friable and difficult to identify. Specimens of similar morphology have been observed in conodont preparations from the Carboniferous to late Triassic of Britain and elsewhere.

- **CR-FV-473. Block 2.**

Lithology: Medium-dark grey, hard, muddy micrite with olive-grey mud clasts.

Sample weight: 340 g.

Conodont elements recovered: None.

Other microfossils: Internal moulds of smooth ostracods are fairly common but lack definitive characters. A few small shells and fragments of larger ones are present. A single "wheel" type holothurian sclerite was recovered and one ?fish scale?. All are very poorly preserved.

Remarks: Despite the recovery of representatives of several fossil groups, nothing diagnostic can be recognised. It is possible that an ostracod specialist could shed more light on specimens of that group.

- **CR-FV-473. Block 3.**

Lithology: Blue-grey micaceous “sugary” siltstone.

Sample weight: 150 g.

No microfossils were recovered from this sample.

- **CR-FV-473. Block 4.**

Lithology: Medium-dark bluish grey fine calcarenite.

Sample weight: 127 g.

Conodont elements recovered: None.

Other microfossils: A single fish tooth.

Remarks: Nothing diagnostic.

- **CR-FV-473. Block 5.**

Lithology: Medium-dark grey calcilutite with olive-yellow mud filled pipes (?burrows)

Sample weight: 114 g.

Conodont elements recovered: None

Other microfossils: A few badly preserved and indeterminate fish dermal fragments.
Possible echinoderm and shell fragments.

Remarks: Nothing diagnostic.

- **CR-FV-473. Block 6.**

Lithology: same as Block 3.

Sample weight: 380 g.

No microfossils were recovered from this sample.

- **CR-FV-473. Block 7.**

Lithology: Medium-dark grey calcarenite with coarser bands.

Sample weight: 240 g.

Conodont elements recovered: One small indeterminate fragment equivocally identified as a distal portion of a ramiform element; preservation so poor that it may not be a conodont. Black.

Other microfossils: None.

Remarks: If the fragment is indeed a conodont element, then it indicates a pre-Jurassic age; it is too poorly preserved for any greater precision.

- **CR-FV-473. Block 8.**

Lithology: Medium grey very fine calcarenite with darker patches, possibly bioturbated.

Sample weight: 170 g.

Conodont elements recovered: None.

Other microfossils: One shell fragment and one fish ?tooth.

Remarks: Nothing diagnostic.

- **CR-FV-473. Block 9.**

Lithology: Medium grey fine calcarenite with olive finer grained burrow infills.

Sample weight: 80 g.

Conodont elements recovered: None.

Other microfossils: A few fish and ?shell fragments. Possible coprolite.

Remarks: Nothing diagnostic.

- **CR-FV-487. Block 1.**

Lithology: Dark grey “sugary” soft fine siltstone.

Sample weight: 390 g.

Conodont elements recovered: None.

Other microfossils: Three ?dermal fragments of fish?

Remarks: Nothing diagnostic.

**Triassic bivalves from the province of
Zamora Chinchipe in SE Ecuador**

Report WH/89/28R - PD 89/28

Geographical index
Ecuador

Subject index
Trias
Mollusca

Dr. J. D. Bennett
Dr. J. A. Aspden
Dr. B. Owens
File: Ecuador

Material

- ES-1A, B** Dark grey calcareous muddy siltstone with pectinacean (no detailed locality data).
P1 Río Timbara, Piuntza, dark grey calcareous muddy siltstone with pectinacean.

ES1A and ES1B also processed (as MPA 26549 and 26550 respectively) for palynology.

The pectinaceans appeared to be late Triassic *Entomonotis* or *Daonella* so were sent to Dr. N. J. Morris (British Museum, Natural History) for comparison with their material.

Dr. Morris commented (20/1/89) "These are all either *Halobia*, *Daonella* or *Entomonotis* and are therefore late Middle to Upper Triassic in age. They are most likely *Entomonotis richmondiana** but are not sufficiently well preserved for me to be certain. There are therefore possibly Norian".

**Monotis (Entomonotis) richmondiana* (Zittel). Treatise on Inv. Palaeontology. N374.

H. C. Ivimey-Cook (from determination by Dr. N. J. Morris)

30 January 1989

Sinemurian ammonites from the Santiago Formation, Ecuador

WH/89/85R - PD/89/81

Geographical index

Ecuador

Subject index

Ammonites

Jurassic

Sinemurian

Dr. J. D. Bennett

Dr. J. A. Aspden

Dr. B. Owens

File: Ecuador

Material: Received unnumbered - they have been given BGS Temporary numbers TNN1415 – 1418D.

Locality: Data received – “New road cutting in Sub-Andean Zone through ?Cutucú uplift. all from the same area in the type section of the Santiago Formation”. See Geyer (1974), Bristow & Hoffstetter (1977).

The ammonites are preserved in two, apparently different, lithologies:

TNN 1415, 1418(a)-(d) in pale brown, rather fissile, muddy, slightly micaceous, non-calcareous siltstone, with flattened ammonites as internal casts and moulds with little evidence of their venters.

TNN 1416, 1417 in dark grey-black strongly calcareous, finely micaceous siltstone with two ammonites as flattened impressions.

Collection data does not indicate if the pale brown siltstone is the result of deep weathering of the dark calcareous siltstone or give any stratigraphic relationship between them.

Geyer (1974) concluded that the ammonites he found in the Santiago Formation were *Arnioceras* and *Coroniceras* from the Lower Sinemurian but the material he illustrated was very poor. These new specimens are significantly better preserved but differ from *Arnioceras* in being finely ribbed down to the innermost whorls (to below 5 mm diameter in some cases). *Arnioceras* normally has smooth inner whorls to larger diameters than this. In *Coroniceras* there is usually also a short section of smooth inner whorls. These ammonites are more closely comparable with Upper Sinemurian Echioceratidae.

The specimens were examined at length by Dr. Howarth in consultation with Professor Donovan and they concluded that they were probably all Echioceratidae and Upper Sinemurian in age.

They identified these as:

TNN-1416 and TNN-1417 – *Leotechioceras* sp. indet.

TNN-1415 and TNN-1418 – ?*Paltechioceras* sp. indet.

However, they consider that there is some residual uncertainty about these identifications - which could be resolved by more and preferably better material and assisted by the collection of other taxa as well. These ammonites are more likely to be of an age equivalent to the *Echioceras raricostatum* Biozone of N.W. Europe than to be of Lower Sinemurian age. However, the taxonomy of these ammonites has been complicated by the description by Erben (1956) of a substantial number of new taxa of ammonites of about this age from Mexico whose distinctiveness is unclear. Due to the residual uncertainty of their taxonomy this collection, as it is now, is probably not worth separate description but gives an interesting comment on the age of this exposure.

References

BRISTOW C. R. y HOFFSTETTER R. (1977) Lexique Stratigraphique International. Amérique Latine. Vol. 5. (2nd Ed.) Centre Nationale de la Recherche Scientifique, Paris.

ERBEN H. K. (1956) El Jurásico Inferior de México y sus amonites. XX Congreso Geológico Internacional México, 3939 pp, 41 pl.

GEYER O. F. (1974) The Lower Jurassic (Santiago Formation) of Ecuador [in German with English notes]. *Neues Jahrbuch für Geologie und Paläontologie Monatshefte*. Hefte 9, pp. 525-514

H. Ivimey Cook (based on determinations and information from Dr. M. K. Howarth and Professor D. T. Donovan)
3 March 1989

**Palynology of two samples from the
Zamora Chinchipe province of S.E. Ecuador**

WH/89/89R - PD/89/85

Geographical index

Ecuador

Subject index

Cretaceous

Ammonites

Dinoflagellate cysts

Distribution:	1.	J. D. Bennett
	2.	J. A. Aspden
	3.	H. C. Ivimey-Cook
	4.	B. Owens
	5.	Biostratigraphy Research Group Files

Work requested by : J. Aspden/H. C. Ivimey-Cook

Samples prepared by : K. L. Kirby

Samples examined by : J. E. Thomas

1. Introduction

Small amounts of rock chipped from ammonite-bearing black shales were prepared for palynological analysis. The ammonites relating to the two samples were identified, in a report by Dr. H. C. Ivimey-Cook, by Dr. M. K. Howorth (BMNH) as belonging to the Mid Albian Subfamily Mojsisoviciinae which occurs widely in Peru, Ecuador, Venezuela and Colombia.

2. Sample details

MPA-30018 Collecting code ER1 - black shale from the headwaters of the Río Nangaritza

MPA-30019 Collecting code CR-FV-842c - black shale from the Río Vergel (float)

3. Palynology

Both samples yielded abundant organic matter dominated by dark amorphous kerogen. This palynofacies is typical of black shales. In order to obtain identifiable palynomorphs the organic residue was subjected to prolonged oxidation with schultz solution and a brief period of ultrasonic vibration.

Both samples were found to contain several specimens of inaperturate pollen (*Araucariacites* spp.) and monocolpate pollen (*Cycadopites*) with the addition of an indeterminate trilete spore in MPA-30018 and bisaccate pollen in MPA-30019. Rare, poorly preserved specimens of the dinoflagellate cysts *Florentinia ?deanei* and *Oligosphaeridium ?complex* were recovered. Very few publications have dealt with Mid Cretaceous dinoflagellate cysts from South America. Those available include Pothe de Baldi and Ramos (1980 and 1983). The latter reports *Florentinia* ssp. and *Oligosphaeridium* ssp., from the Aptian of Argentina. Also of relevance is Davey (1978) who recorded *Florentinia* spp. and *O. complex* in the Aptian/Turonian to Maastrichtian DSDP site 361 off SW South Africa. Comparison has been made with data on Australian Cretaceous microfloras. Morgan (1980), in a major work on the palynostratigraphy of the Australian Early and Middle Cretaceous, gives the range of the former species as commencing in the Early Albian and the range of the latter species as commencing in the Late Neocomian. Both species range up into the Late Cretaceous.

The dinoflagellate cyst evidence, whilst compatible with the ammonite evidence, cannot give more specific age-determinations.

J. E. Thomas
8 March 1989

References

IVIMEY-COOK H. C. (1988) Cretaceous Ammonites from the province of Zamora Chinchipe in southeast Ecuador. *BGS internal report WH/88/416R*.

MORGAN R. (1980) Palynostratigraphy of the Australian Early and Middle Cretaceous. *Memoirs of the Geological Survey of new South Wales, Palaeontology No. 18*.

PÖTHE DE BALDIS D. y RAMOS V. (1980) Las microfloras de la Formación Mayer y su significado estratigráfico, provincia de Santa Cruz, República de Argentina, *2do Congreso Arg. Paleont. y Bioestr. y 1er Congreso Latin. Paleont, Tomo 5*.

PÖTHE DE BALDIS D. y RAMOS V. (1983) Dinoflagelados del Aptiano Inferior de Río Fósiles, Lago San Martín, provincia de Santa Cruz, Argentina. *Revista Española de Micropaleontología*, 15 (3): 427-446.

APPENDIX 10

Field commission reports for the Cordillera Real from north to south

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No. 1789

QUITO, FEBRUARY 28, 1989

TO : GERENTE TÉCNICO

DE : DR. MARTIN LITHERLAND and ING. MIGUEL POZO T.

SUBJECT : Technical Report of geological works on the Laguna San Marcos-Río Sal Si Puedes routes and the Baeza area from January 17 to February 01, 1989

1. INTRODUCTION

1.1 Project context

The Geological Technical Cooperation Project between the governments of Ecuador and Great Britain involves the collection of field data to understand the geology of the Cordillera Real. This aims to establish a model of its formation processes, as well as its relationship with the environments that govern potential mineral resources for future local works concerning the Instituto Ecuatoriano de Minería.

1.2. Objective

The commission that is the subject of this technical report was carried out from January 17 to February 01, 1989. The initially proposed objective was to conduct a geological research traverse from Laguna San Marcos to the bridge over the Río Salado on the Baeza-Lago Agrio highway in the Amazon Region, Napo Province.

Due to access difficulties in the vicinity of the confluence of the Sal Si Puedes River and the Río Azuela, caused by the March 1987 earthquake, it was not possible to continue with the planned works in this area.

For these reasons, it was decided to interrupt activities in that zone to resume the collection of complementary data and geological checks within the metamorphic belt-North Sector, around the town of Baeza.

1.3 Detailed activities

Month	Day	Traverse
January	17	Approach to Laguna San Marcos.
	18	Right bank of the Río Azuela, sampling of fluvial and heavy sediments.
	19 al 22	Approach along the left bank of the Río Azuela
	23	Crossing of the Río Azuela
	24 al 27	Approach over a lava flow and arrival at the confluence of the Río Sal Si Puedes with the Azuela; return to Laguna San Marcos is undertaken
	28	Laguna San Marcos – Papallacta
	29 al 31	Data collection and geological checking between Papallacta and Baeza
February	01	Baeza – Quito

The geological information obtained during the field works included: structural data, rock sampling for subsequent petrographic analysis, and collection of heavy and fluvial sediments, aimed at establishing possible lithological correlations with data collected in previous geotraverses across the Cordillera Real.

1.4. Geography and hydrography

The study areas are characterized by high topographic features and deep valleys, along which torrential tributaries drain.

Among the most important topographic features of metamorphic and volcanic origin are, respectively:

Sara Urco (4676 mamsl) and the volcanoes Cayambe (5790 mamsl), Reventador (3486 mamsl), and Antisana (5704 mamsl), from which part of the hydrography of the studied zone is formed.

The hydrography is composed of the drainage systems of the Azuela-Salado and Papallacta rivers, both tributaries of the Quijos-Coca system.

Among the tributaries of the right bank of the Azuela-Salado are: Quebrada San Pedro, Boquerón, Arturo, and Montoneras rivers; Quebrada Toldadas and San Jerónimo, Cuscungo, Sal Si Puedes, Quebra Canillas, and Clavaderos rivers. Regarding its left bank, there are the Quebradas Quilpajahua (which originates at Laguna San Marcos), Dantocucho, Palmacucho, and Río Soroche; Quebrada Sardinas and Río Sucio.

Regarding the Papallacta-Baeza route, the hydrography is formed by the San Pedro, Chalpi Chico, Chalpi, Cuango, Maspa, Maspa Chico, Cuyuja, and Victoria rivers.



1.5 Climate

The mentioned topographic conditions have an impact on the climate of the region, which varies from cold and frigid in the high zones to temperate in the low zones.

Regarding the frigid climate, temperatures can vary from below zero to 11.9 degrees Celsius, which correspond to altitudinal belts between 3000 and 4000 mamsl, or more (Naranjo P., 1981).

In terms of the temperate climate, it is considered the condition of the external flank of the Cordillera Real, where a very humid variety is found, with temperatures between 12 and 17.9 degrees, corresponding to the altitudinal belt between 1000 and 3000 mamsl.

The rainiest season in the eastern zone of Ecuador, which includes the study area, corresponds to the months of April to October, with higher peaks in the months of May, July, and October. From November to March, the amount of rainfall is lower. In fact, this is the rainiest and most humid region of the country, where more than 250 days of rain per year are recorded.

1.6. Access

From the Olmedo parish, a paved road is followed that leads to Laguna San Marcos, from where a bridle path can be used that passes through the sites: Toldadas, Nanegal, and La Chorrera.

The trail (pica) probably corresponds to agricultural labour by settlers, developed in past years before the Cayambe National Park was officially declared; this trail heads into a lava flow covered by jungle and is gradually lost due to lack of use and/or maintenance within the vegetation.

Remnants of this trail were detected as far as the front of the mentioned lava flow, at the confluence of the Río Sal Si Puedes with the Río Azuela, as far as it was possible to enter. At this site, a landslide occurred, similar to many others in the study area; their characteristics, such as the lack of evidence of plant cover, suggest they were caused by the March 1987 earthquake.

1.7 Work methodology

The following topographic sheets at a scale of 1:50000, edited by the Instituto Geográfico Militar, were used.

- “Nevado Cayambe”, May 1988.
- “OIII-A1”, in process.
- “Papallacta”, February 1983.
- “Baeza”, in process.

And the aerial photographs, LEARJET; PROYECTO CARTA NACIONAL:

from 78.05.31: 6761, 6762, 6763, 6786, 6787.

from 79.01.12: 8649, 8651, 8652.

Additionally, 20 rock samples, 2 heavy sediment samples, and 2 fluvial sediment samples were collected.

1.8 Previous works

In various investigations, several authors have travelled through the vicinity of the zone that is the subject of this report.

Thus, Arguello C. and Díaz L. (1986) studied the southern zone, in the central and southern parts of the El Chaco Sheet at a 1:50000 scale, which corresponds to the sectors: Chonta Loma, the San Juan Chico and San Juan Grande rivers, and others. They also conducted studies in the central and southern sectors of the Díaz de Pineda Sheet, 1:50000 scale, and in the El Reventador Sheet, 1:50000 scale, following the course of the Río Salado, left bank, downstream to the junction with the Río Yaguana.

This work resulted in the preparation of the El Reventador Geological Sheet (1986-1987, in process), which involved work on Palaeozoic metamorphic rocks, Jurassic-Cretaceous volcanic rocks, and Cretaceous sedimentary rocks of the Hollín and Napo Formations, as well as volcanic rocks belonging to the Pan de Azúcar hill and recent deposits.

Similarly, Santamaría W. and Sierra J. (1986) conducted studies within the hydrographic basins of the Río Mira and the Río Aguarico, finally producing the Mariano Acosta Geological Sheet (1986). In this work, rocks ranging from the Precambrian to the Recent were found; structurally, regional thrust faults were identified. The authors also found economic geology characterized by the presence of sulphides, calcite, silica, and phosphates, in addition to gold content, in the terraces of the Cofanes and Aguarico rivers.

Finally, INECEL and several consulting firms conducted geological studies that culminated in the preparation of the Geological Map of El Reventador Volcano (1988). In this work, different lithologies related to basement rocks, volcanic rocks, and loose deposits can be seen, as well as the structural geology of the region, aimed at future engineering works for the Coca-Codo Sinclair hydroelectric project.

1.9 Assigned personnel

Dr. Martin Litherland (Misión Británica).

Ing. Miguel Pozo.

Sr. Oscar Acosta (Driver)

The following day labourers from the Pesillo Commune, Olmedo Parish, were hired as support personnel:

José Elías Catucumbamba, José Elías Guacán, Alfonso Ulcuango, Jorge Guacán, César Ulcuango, Ernesto Campués, Carlos Alfonso Cruz, Juan Antonio Alba.



1.10 Transport

A Jeep Land Rover, license plate AT-0068, belonging to the British Mission, was used from Quito to Laguna San Marcos and then on the Papallacta-Baeza route.

During the course of the works, structural data, rock samples, and heavy and fluvial sediment samples were taken, the details of which are presented in the following chapters.

2. GEOLOGY BETWEEN LAGUNA DE SAN MARCOS AND THE MOUTH OF THE RÍO SAL SI PUEDES AT THE AZUELA

2.1 Introduction

In the studied route, rocks belonging to the volcanic cover related to the Cayambe Volcano were basically observed; to a lesser extent, granitoid and metamorphic basement rocks were seen, as explained below:

2.2 Volcanic rocks

2.2.1 Lahar deposits

Lahar deposits were observed with thicknesses of around 40 meters. These deposits partially cover lava flows and are among the latest geological events occurring during the Quaternary.

In a representative stratigraphic section, at least three levels were observed within the same deposit, whose boundaries are characterized by a notable distribution of large blocks (approximately one meter in diameter) at the base, and finer-grained materials toward the top.

The deposits in question consist of poorly sorted granulometric material, with heterolithic, subangular, and sometimes subrounded blocks.

At the mouth of the Soroche River into the Azuela, a deposit (lh1) was observed, which due to its morphology could correspond to the remains of a previously generated lahar.

2.2.2 Lava flows

Based on the state of erosion and morphology, the identification of three lava flows is inferred: the oldest (lv1), which forms a large part of the divide between the Quebrada Angureal and the Río Arturo.

According to its geomorphology, it appears with highly eroded external forms and is partially covered by a lahar deposit (lh2), which is why the downstream extent of this flow in the Río Azuela is unknown.

Similar to the previous one, between the Río Montoneras and the Quebrada Toldadas, there is another lava flow (lv2) that still preserves the remnant morphology of an eroded lava flow edge; likewise, its downstream extent is unknown, as it is presumably also covered by lahar deposits (lh2).

Another lava flow (lv3), younger than the previous ones, forms the divide between the Sal Si Puedes and Azuela rivers. It is not covered by lahar deposits, which makes visible on its surface lava pressure ridges at a hectometric scale (AERIAL PHOTOS 6786-6787 of 78.05.31). Furthermore, its edges form very steep cliffs up to about 300 m, reasons that suggest this is a younger lava flow than the two previous ones.

The lava flow (lv3?) found downstream of the Azuela, which forms the divide between the Quebracanillas and Clavaderos rivers, also presents lava pressure ridges; it is probably of the same nature and was formed during the same event as the previous one.

2.3 Basement rocks

2.3.1 Granitoid rocks

The following samples are from various sectors (see map) of a plutonic/subvolcanic area along the Río Azuela.

Medium-grained hornblende porphyry (MP-532); massive rock, light grey colour, mottled with dark spots. It contains euhedral crystals of hornblende and twinned plagioclase in a fine-grained matrix composed of the same minerals.

Quartz diorite-type porphyry (533-534AB); leucocratic rock mottled with dark-green spots, massive, contains twinned plagioclase crystals in sub- to euhedral crystals, hornblende in anhedral crystals, pyroxene (?) and anhedral quartz, biotite in euhedral crystals.

Hornblende microdiorite (536); fine-grained leucocratic rock, mottled with dark-green spots. It contains subhedral crystals of amphibole and pyroxene, plagioclase, potassium feldspar, and to a lesser extent, quartz.

Biotitic quartz monzonite (535); leucocratic and massive rock, with an altered surface. It contains minerals of plagioclase, potassium feldspar, biotite, and on a smaller scale, quartz.

2.3.2 Metamorphic rocks

Based on the colour, the external appearance of shearing, and the degree of deformation, the presence of an outcropping of graphitic schist and green schist is estimated, according to observations made on the opposite side of the Río Azuela, at a site that was not possible to reach; structurally, the estimated strike and dip were north-south and 70 to the west, respectively.



In the vicinity of this site, samples of metamorphic rock cobbles were taken with the following characteristics:

Silicified orthogneiss (531A); light-coloured rock, with alternating light and dark bands of quartz (?), in addition to fine muscovite crystals.

Muscovite schist (531B); light-coloured, foliated rock, with minerals of muscovite, quartz, chloritoid, and garnet.

Muscovite and chlorite gneiss (531C); light grey, sheared rock, with light and dark bands; minerals include muscovite, chlorite, and quartz.

3. GEOLOGY OF THE BAEZA AREA

3.1 Introduction

The studies conducted in the surroundings of Baeza were distributed in the following manner:

- (a) Papallacta-Baeza road (2 days).
- (b) South of Baeza to Cosanga (1 day).
- (c) North of Baeza (Río Borja) and south (Río Bermejo) (1 day).

The data from the new results will be included in the geological map at a 1:250000 scale, which will be presented with the third annual report in June 1989.

3.2 The Papallacta-Baeza road, west of the Subandean front

This route was studied by the first commission of the project (Litherland et al., 1986). A revision was necessary due to the discovery of new lithological divisions in the Oyacachi-El Chaco section to the north (Litherland and Pozo, 1988) and the discovery of a tectonic stratigraphy in the Micacocha-Cosanga section to the south (Litherland and Pozo, 1989). One objective was the verification, in the Papallacta-Baeza area, of the tectonic stratigraphy found in the Micacocha-Cosanga section.

Most of the Papallacta-Baeza section up to the sub-Andean front has a “horizontal” tectonic regime (Litherland et al., 1986), the same pattern as the Micacocha-Cosanga section (Litherland and Pozo, 1989). However, through the present revision, the lithologies on the Papallacta-Baeza route can be reclassified in the following manner:

- (a) Papallacta to 1 km: metagranite rocks of the Tres Lagunas type correlated with those of Oyacachi.
- (b) 1 to 4 km: metasedimentary “granoblastic” rocks composed of quartz and violet-pink garnet, with graphitic and quartzose schists; correlated with the same granoblastic belt through Oyacachi.

- (c) 4 to 8.4 km (0.3 km E of the Río Chalpi): foliated/mylonitic orthogneiss with blue quartz cataclasts: correlated with the “mylonitic” Tres Lagunas metagranite belt identified in the Micacocha-Cosanga section.
- (d) 8.4 to 8.7 km: pelitic schist with chloritoid.
- (e) 8.7 to 11.2 km: fine quartzite intercalated with black graphitic phyllite, correlated with the “Loja type” semipelite in the Micacocha-Cosanga section.
- (f) 11.2 to 12.8 km: metagranite similar to the Tres Lagunas granite, with fine aplogranite phases.
- (g) 12.8 to 13.7 km: pelitic schist with chloritoid and garnet.
- (h) 13.7 to 14.3 km: metagranitoid.
- (i) 14.3 to 15.8 km: “Loja type” semipelite.
- (j) 15.8 to 16.5 km: pale phyllite.
- (k) 16.5 to 17.5 km: semipelitic gneiss (Río Cuyuja).
- (l) 17.5 to 20.8 km: black phyllites.
- (m) 20.8 to 25.7 km: pelitic schists (chlorite-muscovite-garnet).
- (n) 25.7 to 31.0 km: green metalavas, green schists, and pelitic schists

This west-east sequence of combined lithologies with the structural pattern (Litherland et al., 1986) can be correlated with the Micacocha-Cosanga and Oyacachi-El Chaco scheme, but at a lower structural level. Thus, it appears that between Oyacachi-El Chaco and Micacocha-Cosanga there is a common structural sequence of “overthrust sheets”, characterized from top to bottom in the following manner: Tres Lagunas type metagranite and underlying skarn, Loja type semipelites, pelitic/graphitic schists, and greenstones.

It should be noted that, apart from rolled blocks of skarn and serpentinite, the Río Quijos also carries blocks of pure white marble and a dolerite, similar to the one identified in the Micacocha-Cosanga section.

3.3 The Papallacta-Baeza road, east of the Subandean front

The sub-Andean front is marked, provisionally, by the change in tectonic regime within the greenstones. This is manifested by a regional change from a subhorizontal regime with second schistosity (S2) to the west, to a subvertical regime with first schistosity (S1) to the east. Near Baeza, there are also outcrops of the Cretaceous Hollín, Napo, and Tena Formations, which are elements of the sub-Andean belt in other parts of the mountain range.

3.4 The Cosanga-Baeza-Borja road

This study was a check of lithology and geological and tectonic contacts for the sub-Andean zone, especially in the sense of the differentiation of rocks of different ages and tectonic domains.



To the east, the contacts of the Abitagua granite (Jurassic, undeformed) with the Sumaco volcanics were reviewed. Further west, a fault was located passing through the vicinity of Borja and the Río Cosanga; this defines the cratonic limit (undeformed) through Jurassic and Tertiary tectonism. Thus, this fault defines the eastern limit of Tertiary deformation in Cretaceous rocks (Hollín, Napo, and Tena Formations) and the eastern limit of Jurassic deformation in the pre-Cretaceous basement.

We also studied the extent of “recent” lavas (Sumaco?) west of the Baeza-Cosanga road, where this unit overlies the black shales of the Napo Formation.

In the town of Borja, below the suspension bridge over the Río Quijos, a rolled block of “migmatite” was located with pegmatitic and granitic veins, some related to tectonic flow drag. This block is the first evidence of migmatites probably from the Precambrian (?), seen in the northern sector of the Cordillera; it likely comes from the cratonic zone, east of the Río Quijos, as a xenolith in the Abitagua granite, or a vein in a fault zone.

3.5 Mineral potential

In terms of geological environments favourable for metallic mineralization, there are serpentinites, in the form of blocks, in the Quijos, Cosanga, and Bermejo (?) rivers. Skarn rock blocks, which come from the Llanganates belt, are present in the Río Quijos upstream from the confluence with the Río Papallacta. Gold was panned in the Río Quijos 100 m downstream from the confluence with the Río Papallacta.

Further east, there are rolled blocks of epidotized metalava within the zone of metavolcanic greenstones. Based on studies to the north (Oyacachi-El Chaco) and to the south (Río Mulatos, Baños-Puyo), a “proto skarn” type rock belt can be proposed, related to a chain of plutonic rocks which includes the Azafrán Complex. Mineralized blocks (with sulphides) have been recognized along this belt.

At 13 km east of the Río Cosanga, in the direction of Baeza, some metamorphic rock blocks were located (greater than 1 m in diameter) composed almost entirely of sericite, which could have utility as a non-metallic industrial mineral.

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Dr. Martin Litherland

Ing. Miguel Pozo T.

CORDILLERA REAL PROJECT



No. 4040

QUITO, MAY 8, 1989

TO : GERENTE TÉCNICO

FROM : DR. MARTIN LITHERLAND and ING. MIGUEL POZO T.

SUBJECT : Technical Report of geological works between La Dormida Valley-Sara Urco and Río Salado-Río El Diviso, from March 7 to 21, 1989

1. INTRODUCTION

1.1 Project context

The Geological Technical Cooperation Project between the governments of Ecuador and Great Britain involves the collection of field data to understand the geology of the Cordillera Real. This aims to establish a model of its formation processes, as well as its relationship with the environments that govern potential mineral resources for future local works concerning the Instituto Ecuatoriano de Minería.

1.2 Objective

The commission that is the subject of this report (summary) was carried out from March 07 to 21, 1989. Its objective was to conduct a geological study in the vicinity of Cerro Sara Urco on one hand, and along the Salado and Diviso rivers on the other.

1.3 Assigned personnel

To carry out this work, it was convenient to form two subgroups with the aim of achieving geological information coverage from two fronts: (a) the sector comprised between La Dormida Valley and the eastern flank of Cerro Sara Urco, and (b) the sector comprised between the bridge over the Río Salado (Baeza-Nueva Loja highway) and the headwaters of the Río El Diviso. These groups were composed in the following manner:

Grupo No. 1: La Dormida Valley-eastern flank of Cerro Sara Urco
Ing. Miguel Pozo

Grupo No. 2: Río Salado-Río El Diviso
Dr. Martin Litherland
Sr. Manuel Céleri

Driver: Sr. Víctor Vega

1.4 Transport

Jeep Land Rover, license plate AT-0068, belonging to the British Mission.

1.5 Detailed activities

The collection of geological information was carried out according to the following breakdown of activities:

Grupo No. 1

Month	Day	Traverse
	07	Quito-Punto Pitaná-La Dormida Valley
	08	Laguna Yanacocha-Río Hualaringo Valley
	09 al 11	Punto "Che-Guevara"-Laguna Azul (Base of Sara Urco)
	14	Through Quimsacocha to the Q. Dantahuañunahuaicu Valley
March	15 y 16	From this site to Pichicavenadopungu point, to cross the alignment zone
	17	Return through the Q. Dantahuañunahuaicu Valley-Resbaladerahuaicu
	18 y 19	Río Hualaringo
	20	Laguna Yanacocha-La Dormida Valley-Punto Pitaná
	21	Return to Quito

Grupo No. 2

Month	Day	Traverse
	07	Quito-Chaco. Hiring of personnel
	08 al 12	Collection of geological information along the right bank of the Río Salado
March	13 al 17	Collection of geological information along the right bank of the Río El Diviso
	18 al 20	Return toward the bridge over the Río Salado
	21	Return to Quito

1.6 Geography and hydrography

The study areas are characterized by having elevated topographic features and deep valleys, along which torrential tributaries drain.

Among the most important regional topographic features of metamorphic and volcanic origin are, respectively:

Sara Urco (4676 mamsl) and, the Cayambe (5790 mamsl) and Reventador (3485 mamsl) volcanoes, from which most of the hydrography of the studied area is formed.

In relation to the Sara Urco area, the relief is very steep, irregular, and abrupt, aspects governed by structural characteristics and erosive factors.



The general hydrography is mainly composed of the Hualaringo rivers and the headwaters of the Sara Urco and Sarayacu; while in the Sub-Andean zone, it is formed by the El Diviso, Yaguana, Cascabel, and Salado rivers, all of which are tributaries of the Quijos-Coca hydrographic system.

It is worth noting that the Río Salado was part of the epicentral zone of the March 5, 1987 earthquake, which generated an area of regional devastation with several thousand victims. While in the Sara Urco zone the devastation translates to numerous landslide sites that do not present access difficulties, in the Río Salado, the effects include fissures up to two meters wide in the jungle terraces and instability in steep sites, which often create difficult and risky situations during access.

1.7 Climate

The mentioned topographic conditions have an impact on the climate of the region, which varies from cold and frigid in the high areas to temperate in the low areas.

Regarding the frigid climate, temperatures can vary from below zero to 11.9 degrees Celsius, corresponding to altitudinal belts between 3000 and 4000 mamsl or more (Naranjo P., 1981), characteristics existing in the vicinity of Cayambe and Sara Urco.

Concerning the temperate climate, it is considered the external flank condition of the Cordillera Real, where a very humid variety is found, with temperatures between 12 and 17.9 degrees Celsius, corresponding to the altitudinal belt between 1000 and 3000 mamsl, where the Salado-El Diviso zone is located.

The rainiest season in the eastern zone of Ecuador, which includes the study area, corresponds to the months of April to October, with higher peaks in the months of May, July, and October. From November to March, the amount of rainfall is lower. In fact, this is the rainiest and most humid region of the country, where more than 250 days of rain per year are recorded.

1.8 Access

For the Sara Urco zone, it is possible to follow a cobblestone road from the Juan Montalvo neighbourhood in Cayambe to the ecological reserve checkpoint of the Ministry of Agriculture, where it forks; from this point, one can continue on foot and/or using horses along the path on the right through the La Dormida Valley.

From the headwaters of the mentioned valley, one must descend to the Río Hualaringo valley and then ascend along the right bank to the headwaters of the Q. Resbaladerahuaicu, where Sara Urco is located. Along one of the streams that descend from the lagoons, one can reach the Q. Dantahuañunahuaicu, at whose headwaters lies the domain of the Sara Urco fault alignment.

For the Salado-Diviso zone, the approach is made via the highway that connects the towns of Baeza and Nueva Loja; from the bridge over the Río Salado, it is possible to continue on foot for the entire journey to the headwaters of the Río El Diviso.

1.9 Work methodology

For both zones, the following topographic sheets at 1:50000 scale were used, published by the Instituto Geográfico Militar.

- “OIII-A1b y d”, in process
- “Río Hualaringo”, May 1978
- “Río Cascabel”, May 1978

And the aerial photographs, LEARJET; PROYECTO CARTA NACIONAL:

- 7600, 7601 y 7602
- 8843, 8844 y 8845

During this commission, structural data were taken, and approximately 100 rock samples, 13 heavy sediment samples, and 7 fluvial samples were collected.

1.10 Previous works

In different previous investigations, various authors have travelled through the vicinity of the area that is the subject of this report.

Thus, Barragan J. (1986) conducted studies in the vicinity of Sara Urco, in which three lithological units were identified, consisting of the Ambuquí Group, with sericitic schists, quartzites, and amphibolites, crossed by milky quartz veinlets. The Altar Group, composed of andesites, obsidians, mafic lavas, volcanic ash, tuffs, and pumice. Regarding glacial deposits, reference is made to aspects related to this topic in the vicinity of Sara Urco. Economically, the author detected the presence of pyrite, chalcopyrite, bornite, and argentite; however, he notes the absence of gold.

Arguello C. and Díaz L. (1986) studied the southern zone, in the central and southern part of the El Chaco sheet at 1:50000 scale, corresponding to the sectors: Chonta Loma, the San Juan Chico and San Juan Grande rivers, and others. They also conducted studies in the central and southern sectors of the Diaz de Pineda sheet, scale 1:50000, and in the El Reventador sheet, scale 1:50000, following the course of the Río Salado, left bank, downstream to the junction with the Río Yaguana.

This work resulted in the preparation of the El Reventador geological sheet (1986-1987, in press), in which work was done on Palaeozoic metamorphic rocks, Jurassic-Cretaceous volcanic rocks, and Cretaceous sedimentary rocks of the Hollín and Napo formations, and volcanic rocks belonging to the Pan de Azúcar hill and recent deposits.

Similarly, Santamaría W. and Sierra J. (1986) conducted studies within the Río Mira and Río Aguarico drainage basins aimed at the preparation of the Mariano Acosta geological sheet (in press).

In this work, rocks were found ranging from the Precambrian to the Holocene; structurally, regional thrust faults were identified. The author also found an economic geology characterized by the presence of sulphides, calcite, silica, and phosphates, in addition to gold content in the terraces of the Cofanes and Aguarico rivers.



INECEL and several consulting firms carried out geological studies that culminated in the preparation of the Geological Map of El Reventador Volcano (1988). In this work, several lithologies related to basement rocks, volcanic rocks, and unconsolidated deposits are differentiated, as well as the structural geology of the region, aimed at future engineering works for the Coca-Codo Sinclair hydroelectric project.

Lastly, Litherland M. and Pozo M. (1989) conducted a geological reconnaissance between San Marcos Lagoon and the Río Sal Si Puedes.

2. GEOLOGY BETWEEN LA DORMIDA VALLEY AND THE EASTERN FLANK OF CERRO SARA URCO (MAP 1)

2.1 Introduction

Toward the west of the investigated area, rocks from the volcanic cover of Cayambe Volcano were observed, and mainly metamorphic and granitic rocks toward the east. Chronologically, the latest geological manifestations are represented by colluvial and alluvial deposits and landslides induced by the March 1987 earthquake. The economic aspect was represented by evidence of marble, pyrite, magnetite, and sulphides. Gold was not detected.

2.2 The Quaternary

2.2.1 Recent landslides

One of the effects of the March 1987 earthquake was landslides, whose traces are present in the region as a testimony to the seismic phenomenon in question, especially in the valleys of the Río Hualaringo and the Quebradas Dantahuañunahuaicu and Resbaladerahuaicu, as well as on the steep slopes of Ingaumasacha.

The course of the Río Salado, downstream, is located in the vicinity of the epicentre of the March 1987 earthquake, which constitutes an area of regional devastation; the effects that are still visible in the field include fissures up to two meters wide in the jungle terraces and much unstable ground that presents difficulties and risk in accessing this sector.

2.2.2 Volcanic ash (Cz)

These cover almost the entirety of the investigated area, with the exception of very steep sites. They are characterized by a dark brown tuff with light ash intercalations, with a visible thickness of about two meters.

2.2.3 Alluvial deposits (Qal)

Present especially in the courses of the Hualaringo and La Dormida rivers, due to the continuous contribution of abundant detritus from the foothills of Cayambe.

2.2.4 Colluvial deposits (c)

Originated by the fall of materials from steep areas, especially at the foot of escarpments produced by modern lava flows from Cayambe.

2.2.5 Glacial geology (M)

It is represented by long U-shaped valleys, glacial steps, cirques, lateral, ground, and recessional moraines; these morphological features are found especially in the following valleys: Río Hualaringo, Q. Dantahuañunahuaicu, and Q. Resbaladerahuaicu, in which it is common to find outcrops with glacial striations. Other geomorphological features are horns (Sara Urco can be considered within this category), arêtes (at the Pichicavenadopungu site), and lagoons of glacial origin (Yanacocha Grande, Yanacocha, Azul, Verde, etc.).

2.2.6 Lava flows (V)

Andesitic lava flows outcrop in extensive areas toward the northwest of the study zone. At the headwaters of the La Dormida Valley, and on the left bank of the Río Hualaringo toward the north, there is evidence that the lava flows have been cut by the erosive action of glaciation. This implies that the glaciation was subsequent to the deposition of such flows and, therefore, their age can be considered greater than 10000 years.

2.2.7 Other volcanics (b)

These are found cutting the Andean foliation in dikes of centimetre and decimetre scale thickness; they have been observed on the right bank of the Río Hualaringo. They have a massive appearance, a dark grey colour, are sometimes mineralized, and show no traces of tectonism; it is not possible to clearly distinguish the presence of phenocrysts. They probably belong to the last phases of volcanic activity of Cayambe (?).

2.3 Basement rocks

2.3.1 Granitoid rocks

Metagranite boulders (Xgg), probably associated with the Tres Lagunas granite, were found in the alluvial deposits of the Río Hualaringo and in the Q. Resbaladerahuaicu; this lithology was also identified in outcrops located in the stream that descends from Laguna Lagoon, on the left bank of the Q. Dantahuañunahuaicu and at its headwaters.

In hand specimens, feldspars and quartz are identified as main constituents; in others, there are muscovite and biotite; likewise, they sometimes present incipient shearing.

2.3.2 Metamorphic rocks

2.3.2a Schists (Xs)

Many varieties of schists have been found, whose mineralogical components include: muscovite-graphite (Xsmr), muscovite (Xsm), on the right bank of the Q. La Dormida, among the debris of a recent landslide; muscovite-chloritoid (Xsmcl), quartz-chloritoid (Xsqcl), muscovite-biotite-chlorite (Xsmbic), tourmaline (Xstu), chlorite-quartz (Xscq), and biotite (Xsbi) on both banks of the Río Hualaringo and in the Quebradas Resbaladerahuaicu and Dantahuañunahuaicu; quartz-muscovite (Xsqm), in fallen blocks among the debris of a recent landslide at the headwaters of the Río Sara Urco and in another landslide on the right bank of the Q. Dantahuañunahuaicu; actinolitic schist (Xsac), as subangular fallen blocks on the western flank of Sara Urco.



Near the mouth of the Q. Resbaladerahuaicu at the Río Hualaringo, blocks (around 3 cm in diameter) with fuchsite mica were found.

Toward the east of the Sara Urco fault, at the headwaters of the Q. Dantahuañunahuaicu, outcrops of muscovite-chlorite schist (Xsmcl), with muscovite-graphite-tourmaline (Xsmrtu) and quartzites (Xq), were located.

2.3.2b Carbonate rocks (XI)

On the western flank of Sara Urco (Map 1), grey marble was identified in subangular blocks of up to 80 cm in diameter.

2.3.2c Skarn, epidotic rocks, and amphibolites (K)

Fallen blocks of skarn were found among the debris of a recent landslide; the constituent minerals include: garnet, epidote, amphiboles, and sometimes sulphides.

Similarly, epidotic rocks were found both in fallen blocks and in outcrops. Probably, the skarns and epidotic rocks are associated. Mineralogically, they are composed of epidote and, in some cases, mineralizations appear.

Amphibolitic rocks were found in the landslide on the right bank of the Río Sara Urco (headwaters); also, among the boulders of the Q. Laguna Seca, at its mouth with the Río Hualaringo.

2.3.2d Metavolcanic rocks (Xv)

Greenstones of meta-andesitic composition were located at the eastern end of the study area. The appearance ranges from massive to schistose, of greenschist facies.

2.3.3 Pegmatitic rocks (Xpeg-peg.tu)

These are represented by schists with high muscovite content and high tourmaline content, and quartz-feldspar-tourmaline micropegmatites, located in fallen blocks on the western flank of Sara Urco; pegmatitic outcrops also exist on the right bank of the Quebrada Dantahuañunahuaicu.

2.4 Structural geology

The main structural feature is located toward the east of Sara Urco, through an alignment perfectly visible in aerial photographs, which has been named the Sara Urco fault, and which crosses the study area with a NE-SW orientation and an estimated dip of 50° toward the west; it is probably associated with the tectonic foliation.

From west to east, changes in the dip of the foliation are defined: around 40°, then an abrupt change in inclination (between 70° and 80°), and finally gentle angles between 30° and 40°, which, in general terms, suggests the existence of a monoform.



There are still not enough data to establish a synform in the surroundings of Sara Urco that are correlatable with the Urcucocha synform of the Laguna Micacocha-Cosanga route (Litherland and Pozo, 1989).

3. GEOLOGY OF THE SECTOR COMPRISED BETWEEN THE RÍOS SALADO AND DIVISO (MAP 2)

3.1 Introduction

The Río Salado-Diviso section is located in the Sub-Andean zone, within the Western belt (Litherland, 1988). It comprises a mixture of basement rocks of Jurassic age (?) and rocks from Cretaceous formations, separated by tectonic thrust contacts.

3.2 Plutonic and metaplutonic rocks

A calc-alkaline plutonic suite occurs in the form of boulders in the Río Salado and the Yaguana, Cascabel, and Diviso tributaries. Likewise, two belts of sheared diorite-type rock outcrops with epidotic zones and metadiorite were found in the Río Diviso; their contact with the porphyry shows a 20 cm medium-grained greenish zone, interpreted as a cooling zone of diorite against the porphyry. The proportion of plutonic boulders in the Río El Diviso indicates that this suite predominates further upstream.

The suite is dominated by blocks of gabbros, hornblendites, granodiorites, and diorites, with fine-to-medium-grained mafic igneous xenoliths and their deformed gneissic equivalents; in some cases, the pegmatitic hornblendes reach 10 cm in length, without preferential orientation. There are also deformed granitic rocks, coarse-grained, with grey quartz.

3.3 Porphyries and metaporphyries

On the western side of the Río Salado, upstream along the Río Diviso, there are several belts of porphyry and metaporphyry type rocks. The Río Salado outcrops include medium-grained feldspathic rocks, without mafic minerals, partially or totally altered to kaolin.

With the approach to the dioritic pluton, these rocks change to more quartzose types. To the east of the pluton, the two porphyries are more sheared and intercalated (tectonically?) with schists.

3.4 Schists

Black schists (graphitic) and green schists (chloritic), intercalated with greenstones (amphibolitic?) and metaporphyries (above), outcrop in a tectonized/mylonitic zone on both banks of the fault that passes through the Río Diviso.



3.5 Other metamorphic lithologies in blocks

In the Salado-Diviso rivers, there are calc-silicate blocks as well as white and grey marble; while garnet and epidote skarn was identified in the Diviso and dolomite/chert in the Salado.

3.6 “Misahuallí Member” (Jurassic)

Along the Nueva Loja-Baeza road, the “Misahuallí Member” is composed of andesitic and rhyolitic lavas, agglomerates, etc.

Along the Río Salado, between the Yaguana and Cascabel rivers, there are outcrops of deformed volcanic rocks, which must belong to the Misahuallí Member; they consist of green tuff lavas and purple porphyries with calcite and quartz veins, subparallel to the shear foliation and with autobrecciation and epidotization.

Blocks found in the Río Salado and its westernmost tributaries demonstrate stages of increased tectonism and metamorphism of the Misahuallí member lithologies, through:

- (a) Deformed red and green agglomerates
- (b) Epidotized purple lava vein breccias
- (c) Cleaved green metavolcanics

3.7 Cretaceous Formations

The Hollín, Napo, and Tena Formations outcrop along the Río Salado with deformed and non-deformed characteristics, north and south of the Río Yaguana, respectively.

3.8 Structures

The basement rocks (Jurassic?), the Misahuallí Member (Jurassic), and the Cretaceous formations are affected by Tertiary thrust faults, associated with local penetrative deformation and regional shearing. Thus, the geological map can be interpreted as a sequence of reverse faults, thereby exposing lower structural level rocks to the west.

4. ECONOMIC GEOLOGY

4.1 Occurrence of metallic minerals

4.1.1 Gold

In the Sara Urco zone (Map 1), several attempts were made in some streams, creeks, and rivers along the route, without positive results (as a historical note, the labourers/guides commented on work carried out by adventurers several years ago, as testimony of which an artifact used as a tool for washing lagoon sediments was found). In the Q. Resbaladerahuaicu, several “fresh” sampling sites were found, presumably to search for this metal.

In relation to the Salado-El Diviso zone, gold was found in the alluvial deposits of the Río Yaguana (Map 2) and in the Río Salado (upstream), in the form of a subrounded flake 2 mm in diameter in a terrace 10 m thick.

4.1.2 Pyrite

At the headwaters of the Río Sara Urco (Map 1), in a landslide on the right bank, blocks with pyrite in euhedral crystals up to 2 cm in diameter were observed, associated with quartz and chlorite.

Regarding the Salado-Diviso zone (Map 2), the porphyry outcrops are rich in fine pyrite.

4.1.3 Chromium

Near the mouth of the Q. Resbaladerahuaicu at the Río Hualaringo, blocks (around 3 cm in diameter) with fuchsite mica were found.

4.1.4 Magnetite

In the landslide located at the headwaters of the Río Sara Urco, a highly magnetic block (3 cm in diameter) was found.

4.2 Occurrence of non-metallic minerals

4.2.1 Kaolin

The decomposition of the porphyry rock, which in the outcrop near the Río Salado (Map 2) appears to be pure feldspar, forms deposits rich in kaolin.

4.2.2 Carbonate

On the western flank of Sara Urco (Map 1), grey marble was identified in subangular blocks up to 80 cm in diameter.

In the Río Salado (Map 2), Río Diviso, and Arroyo del Tuerto, there are blocks of pure white medium-to-coarse-grained marble and pale grey marble. The blocks do not exceed 1 m.

There is carbonate in the form of limestones from the Napo Formation.

4.2.3 Graphite

In the Arroyo del Tuerto (Map 2), there are bands up to 1 m thick of high-purity graphite rock.

4.2.4 Oil

Upon breaking a block (Map 2), there was an odour of petroleum from a limestone sample of the Napo Formation.



4.2.5 Tourmaline

It was found in massive and schistose blocks. In the first case, it occurs in micropegmatites with black tourmaline crystals up to 6 mm in length, associated with subhedral, equigranular feldspar crystals. In the case of the schists, the tourmaline is in disordered crystals, apparently subordinate to the foliation planes.

The absence of deformation in the massive blocks and the occurrence of non-deformed tourmaline in the schists indicate that this mineral formed in stages subsequent to tectonism, related to late pegmatitic events.

Regionally, the presence of tourmalinite related to the El Placer skarnfield, about 100 km south of Sara Urco (Litherland, 1988), should be highlighted.

5. MINERAL POTENTIAL

5.1 Skarn rocks

As is known, the importance of skarn rocks lies in their economic potential through a wide range of metallic minerals. From the studies carried out by the Cordillera Real Project to date, it has been possible to define a series of fields that can be integrated into a regional skarn belt, which has been given the name Llanganates skarn.

Such is the case of the El Placer field (Litherland and Bermudez, 1987), in the headwaters of the Río Mulatos; the Urcucocha field, defined in the Laguna Micacocha-Cosanga route (Litherland and Pozo, 1989); boulders found in the Río Quijos (Litherland and Pozo, 1989) tend to define the presence of outcrops in upstream sites; similarly, the skarn blocks found in the Río Chalpi (tributary of the Río Oyacachi), in the Oyacachi-Chaco route (Litherland and Pozo, 1987).

Finally, the discovery of evidence of a new skarnfield, found among the debris of a landslide at the headwaters of the Río Sara Urco, is important as it tends to strengthen the idea of the regional skarn belt in northern zones, completing at the moment an approximate length of 150 kilometres; although only blocks of magnetite and pyrite were identified, the possibility that a polymetallic potential exists in this skarn is not ruled out.

Regarding the Salado zone, the skarn blocks in the Río Diviso are scarce and derived from a distant belt, probably associated with the calc-silicates and marbles. The regional drainage indicates that the skarnfield cannot correspond to the evidence found west of Sara Urco.

5.2 The porphyries

They form units up to 1 km wide, always with considerable pyrite. The porphyries constitute candidates to be considered as a source of sub-Andean gold.

5.3 Tourmaline micropegmatite

The presence of this mineral indicates the occurrence of boron metasomatism and the possible concentration of economic minerals of the pegmatitic type.

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Ing. Géol. J. Miguel Pozo T.

Dr. Martin Litherland

CORDILLERA REAL PROJECT



No. 7149

QUITO, NOVEMBER 21, 1988

TO : GERENTE TÉCNICO

FROM : DR. MARTIN LITHERLAND and ING. MIGUEL POZO T.

SUBJECT : Technical report of the commission carried out in the provinces of Pichincha and Napo, from October 04 to 18, 1988

1. INTRODUCTION

1.1 Project context

The technical collaboration project between the governments of Ecuador and Great Britain involves the collection of field data to understand the geology of the Cordillera Real. This is aimed at establishing a model of its formation processes, as well as its relationship with the environments that govern potential mineral resources for future local work by the Instituto Ecuatoriano de Minería.

1.2 Objective

The commission, which is the subject of this report, was carried out from October 04 to 18, 1988; its objective was to conduct a geological research traverse through the Río Oyacachi valley, from the Cochapamba settlement in the province of Pichincha to the town of El Chaco in the province of Napo.

The geological information collected during this traverse included structural data, rock sampling for subsequent petrographic analysis, and the collection of heavy and fluvial sediments in areas of potential economic interest. All these efforts were aimed at establishing possible lithological correlations with data collected during previous geotraverses in the Cordillera Real.

1.3 Hydrography, geography and topography

The area is characterized by high topographic relief and deep valleys, along which torrential rivers drain, such as the Oyacachi and its tributaries: the Cariyacu, Chalpi, Cedro, Santa María, San Juan Grande, and Chico. Thus formed, the Río Oyacachi eventually drains into the Río Quijos.

Among the geographic features that characterize the region are Cerro Puntas, Loma Yaragala, Chimborazo Tola, Quiscatola, etc., whose altitudes are around 4000 mamsl, forming the drainage divide in the páramo zone of the Cordillera Real; there, it is very common to find valleys and lagoons of glacial origin; in one of these valleys, the town of Oyacachi is located.

From this high zone, the topography begins a continuous and sometimes abrupt descent toward the sub-andean region, within the investigation area, down to altitudinal levels of around 1600 mamsl.

1.4 Climate

The mentioned topographic conditions have an obvious impact on the climate of the region, which varies from cold in the high zones to temperate in the low zones; in the former, temperatures can vary from 0 to 11.9 degrees Celsius, which in turn corresponds to altitudinal belts between 3000 and 4000 mamsl.

In the latter, conversely, the condition of the external flank of the Cordillera Real is considered, where the very humid variety is found, with temperatures between 12 and 17.9 degrees Celsius, corresponding to the altitudinal belt between 1000 and 3000 mamsl.

The rainiest season in the eastern zone of Ecuador, which includes the study area, corresponds to the months from April to October, with higher peaks in the months of May, July, and October. From November to March, the amount of rainfall is lower. In fact, this is the rainiest and most humid region of the country, where more than 250 days of rain per year are recorded.

1.5 Socio-economic aspect

The inhabitants of the town of Oyacachi are organized into a community that dedicates its time to agriculture, livestock, and, although on a small scale, trout fishing.

The manufacturing of wooden troughs and spoons is typical of the sector, for which they use the variety of tree known as alder.

1.6 Access

From the town of Cangahua, in the Cayambe canton, Pichincha province, the road is taken to the Cochapamba hamlet. This road, in its final stretch, is not gravelled, which is why during rainy seasons it becomes very slippery and difficult for vehicle access; from there it is possible to reach Oyacachi, crossing the páramo on foot and/or using mules.

There is a bridle path that joins Oyacachi with the confluence of the Río Cedro and the Oyacachi. The Carihuaycu and Chalpi rivers, in the middle of said route, have relatively recently constructed suspension bridges; however, the Río Cedro can be crossed by pulley via a cable installed there for this purpose.



Once this obstacle is overcome, there is a trail, neglected since the earthquake of March '87 that affected this area, which in certain sectors has been lost and requires the use of machetes, especially in the Sisahua area, the Quebrada del Muerto, and even near the Río Santa María.

Finally, it is possible to cross the Río Santa María on foot (when it is not swollen) and/or by using a cable and pulley.

From there, it is possible to follow a bridle path until near the town of El Chaco, where work has begun aimed at opening a road suitable for motor vehicles.

1.7 Work methodology

The following 1:50000 scale topographic sheets edited by the IGM were used:

CT-ÑIII-B4-3993-II	“Oyacachi”
CT-OIII-A3-4093-III	“Santa Rosa de Quijos”
CT-ÑIII-B2-3993-I	“Cangahua”

And aerial photographs 7606 and 7775 (El Chaco zone, without roll or line), 7111 and 7112 (VM 1370PMW AF60-16 8 FEB65 R-78); 8845 and 8847 (R-43 LEARJET, 18-1-79, PROYECTO CARTA NACIONAL).

The collection of 36 rock samples, 7 fluvial sediment samples, and 12 heavy sediment samples was carried out.

1.8 Assigned personnel

Dr. Martin Litherland
Ing. Miguel Pozo T.
Sr. Manuel Céleri (Driller)
Sr. Luis Villacís (Driver)

1.9 Transport

Jeep Land Rover plate AT-0068, belonging to the British Mission, from Quito to the Cochapamba hamlet and from El Chaco to Quito.

On foot and using mules from Cochapamba to the confluence of the Río Cedro with the Oyacachi, and exclusively on foot from said confluence to the town of El Chaco.



1.10 Detailed activities

Month	Day	Traverse
October	04	Departure from Quito, arrival at Cochapamba.
	05	Traverse from Cochapamba to Oyacachi.
	06	Route from Oyacachi to the first camp.
	07	Route from the first camp to the confluence of the Río Cariyacu and the Río Oyacachi.
	08	Route from the confluence of the Río Cariyacu and the Oyacachi, upstream along the Río Cariyacu to its confluence with the Río Sarayacu.
	09	Route from the confluence of the Iguinto with the Sarayacu, upstream along the Iguinto.
	10	Route from the confluence of the Cariyacu with the Oyacachi, downstream toward the Río Chalpi.
	11	Route from the confluence of the Río Chalpi with the Oyacachi to the Río Cedro.
	12	Route from the confluence of the Río Cedro with the Oyacachi to the Sisahua area.
	13	Route from the Sisahua area to the confluence of the Río Santa María and the Oyacachi.
	14	Route from the confluence of the Río Santa María to the town of El Chaco.
	15	Journey along the highway from El Chaco to the Río Salado, for the purpose of obtaining logistics data for the next geo-traverse from Laguna San Marcos, via the Río Salado, to the Baeza-Lago Agrio highway.
		Another journey was also conducted to the Río Cosanga area, with the objective of determining logistical possibilities for another geo-traverse from Antisana, via the Río Cosanga, to the town of the same name.
	16 y 17	Journey from Baeza to Papallacta, in order to establish the reconnaissance of some geological characteristics, equivalent to the Oyacachi-El Chaco geological cross-section, which is the subject of this report.
	18	Return to Quito.



1.11 Previous works

The Oyacachi area has been previously studied by several groups from the DGGM, now INEMIN (Orellana and Torres, 1980, 1981; Torres, 1981).

Petrographic studies have also been carried out by members of the Escuela Politécnica de Quito (P. Duque, personal communication).

2. GEOLOGY

2.1 Introduction

The geological information comes from outcrops and fallen blocks from the heights on the north side of the Río Oyacachi. This description is objective and without the support of microscopic studies.

2.2 Granitoid rocks

2.2.1 Tres Lagunas type metagranite

About 2 to 4 km east of Oyacachi, the blocks are dominated by a metagranite/metagranodiorite with smoky blue quartz. The rock is coarse-grained and contains epidotized plagioclase and muscovite/?biotite. There is a tectonic foliation. Few blocks of this material were observed east of the Río Cariyacu, and there are also few rolled blocks in the Cariyacu.

This metagranite is provisionally correlated with the Tres Lagunas suite of S-type metagranites which form a chain along the Cordillera Real east of the Baños front (Litherland, 1988).

2.2.2 Río Cedro pluton

About 3 km east of the Río Cedro, there is a metamorphosed, coarse-grained pluton with a predominantly leucocratic appearance and a quartz-monzonitic to granodioritic composition. Blocks in the Río Cedro indicate the presence of igneous xenoliths. It appears that along the margins there are metadiorites with more intense foliation and an augen gneiss appearance.

The location and composition of the Río Cedro pluton are similar to those of the Azafrán pluton to the south in the Cordillera Real. There are no plutonic rocks along the same heading by the Papallacta-Baeza highway, and therefore the Río Cedro pluton may be the northern extension of a chain of Azafrán-type plutons.

2.2.3 Aplites

Leucocratic quartz-feldspathic igneous rocks of medium grain outcrop 1.5 km west of the Río Santa María. They are probably “intercalated” with the local volcanosedimentary sequence.

2.2.4 Pegmatites

Pegmatite blocks are found about 3 km east of Oyacachi. There are quartzose cores 10 cm wide with margins of albite and K-feldspar.

Upstream in the Río Cariyacu (see map) there are pegmatite blocks of feldspathic-chlorite composition, without quartz.

2.2.5 Other granitoids

Between the Cariyacu and Cedro rivers there are several indicators of metagranitoids with a composition generally ranging from granodiorite to diorite (see map).

2.3 Metasedimentary rocks

2.3.1 Pelitic schists

This lithology dominates several sectors between Oyacachi and the Río Cedro. It comprises muscovite and quartz schist with or without chlorite, biotite, chloritoid, garnet, and graphite. They are pale in colour (muscovite), green (chlorite), or grey (graphite).

2.3.2 Graphitic schists

These dominate a sector of about 2.5 km between the Oyacachi and Cedro rivers.

2.3.3 Quartzites

West of the Río Cedro, the quartzites are fine-grained, pale in appearance, and of orthoquartzitic composition. Normally, this lithology is found interstratified with pelitic rocks in semipelitic sequences. However, there are orthoquartzite escarpments without pelitic bands in the Río Cariyacu region.

2.3.4 Metawackes

Clastic sedimentary rocks of “wacke” type with medium to coarse-grained quartz grains are intercalated with metavolcanic rocks west of the Río Cedro pluton.

2.3.5 Semipelites: paragneiss and “granoblastic” rocks

East of the Tres Lagunas-type metagranite (orthogneiss) belt, the presence of blue quartz and/or smoky quartz continues in “granoblastic” rocks of sedimentary, not igneous, origin. The composition is essentially quartz-garnet (strong pink colour). Further east, these transition into muscovite-garnet paragneisses with bands of up to 20 cm of pale orthoquartzite, with (blocks) of orthogneiss.

It is interesting that the occurrence of blue quartz is restricted to a belt that comprises both igneous and sedimentary metamorphic rocks.

2.3.6 Impure marble

There is a stream (see map) where the boulders are mostly coarse-grained, granoblastic grey impure marble with an abundance of free carbonate. There are also boulders in the Chalpi and Quijos rivers of dark banded marbles.



2.4 Basic rocks

“Greenstones” of meta-andesite or metabasalt type dominate the geology east of the Río Cedro pluton as far as the Río Santa María. There are also less deformed/metamorphosed outcrops SE of the Río San Juan Chico, which can be correlated with the Misahuallí volcanics. West of the Río Cedro pluton there are “greenstones” in the form of pre-metamorphic dikes within the pelitic schists; and there are also amphibolite blocks associated with the Tres Lagunas type metagranite.

In the Río Chalpi there are boulders of mafic material in the form of breccia, of meta-agglomerate type.

2.5 Ultrabasic rocks

Boulders of serpentinites were observed in the Río Oyacachi, downstream from the Río Cariyacu, and in the Cariyacu. Going up the Cariyacu in search of outcrops, we found a block measuring 2×1×1 m about 2 km upstream (see map). Further upstream from the junction with the Río Sarayacu, there are no serpentinite blocks in the Río Cariyacu.

It is assumed that the blocks come from the serpentinitic belt noted to the south along the Cordillera Real, between the Pastaza and Papallacta rivers (Litherland, 1988). In the final days of the commission, we observed serpentinite blocks in the following rivers:

- (a) Río Quijos, near the Baeza gas station.
- (b) Río Quijos, blocks up to 4×4×2 m, upstream from the junction with the Río Papallacta.
- (c) Río Chalpi, at the junction with the Río Papallacta.
- (d) Río Cosanga, below the Cosanga bridge.
- (e) Río Aliso, about 2 km upstream from the junction with the Río Cosanga.

All these observations are of serpentinite blocks of the same appearance: massive and mottled olive-green. There is now evidence that all the large rivers that drain the Cordillera Real for a long stretch (150 km) carry serpentinite boulders (Pastaza, Jatunyacu, Cosanga, Quijos, Oyacachi).

2.6 Skarn or epidote type rocks

(See 3.3.1)

2.7 Cretaceous formations

Boulders of red and black slates are found, probably derived from the Tena and Napo Formations of Cretaceous age, east of a stream, 1 km west of the Río Santa María. Information from the private sector indicates that these Formations are part of a series of thrusts with eastward movement in the Río Oyacachi, west of El Chaco.



2.8 Structural geology

To the west of the Río Cedro pluton, in the metamorphic complex, the rocks have polyphasic structures. The first tectonic plane (schistosity, cleavage) is already almost destroyed by the second (D2), which forms the dominant penetrative schistosity. Microfolds of D2 plunge to the north at low angles. The second schistosity mostly has an Andean strike with a westward dip. No eastward dips were observed, but there are several sectors with subhorizontal dipping indicating the existence of later large-scale folds (D3 or D4) with an Andean strike, which can be verified by minor monoclinal folds with gentle plunging. There is also a crenulation cleavage (D3 or D4) in some schist outcrops.

East of the Río Cedro pluton, the sequence of “greenstones” and metawackes has a single penetrative cleavage, with eccentric strikes and dips. It is possible to correlate this foliation with that affecting the Cretaceous Formations, meaning a foliation of Cenozoic age.

On the map, the line that divides the complex zone (two or more penetrative schistositities) from the zone with a single cleavage is designated as the “Subandean front”, the same as in the southern geo-traverses.

2.9 Metamorphism

The rocks to the west of the “Subandean front” have minerals characteristic of Barrow-type metamorphism of high-grade greenschist facies (garnet, biotite, chloritoid, muscovite). It is possible that the Tres Lagunas granite sector and the granoblastic/paragneiss rocks are of higher grade; amphibolites have also been observed. Thin section studies will indicate if this is correct.

East of the “Subandean front”, the rocks are of lower grade, of phyllite and slate type.



3. ECONOMIC GEOLOGY

3.1 Occurrences of metallic minerals

3.1.1 Gold

The following table indicates the presence of panned gold in the area:

Sample Number	River and Location	Number of gold specks
92	Río Oyacachi, near the town of Oyacachi (Nuevo).	0 (two pans)
93	Río Oyacachi, 300 m upstream from the confluence with the Río Cariyacu.	2 (one pan)
94	Río Cariyacu, 40 m upstream from the confluence with the Río Oyacachi.	1 (one pan)
95	Río Chalpi, 100 m upstream from the confluence with the Río Oyacachi.	0 (two pans)
96	Río Oyacachi, 50 m upstream from the confluence with the Río Chalpi.	1 (one pan)
97	Río Cedro, 100 m upstream from the confluence with the Río Oyacachi.	0 (two pans)
98	Río Oyacachi, ca. 3500 m upstream from its confluence with the Río Santa María.	7 (one pan)
99	Río Santa María, 400 m upstream from its confluence with the Río Oyacachi.	1 (one pan)
100	San Juan Grande River, 400 m upstream from its confluence with the Río Oyacachi.	2 (two pans)
101	Río San Juan Chico, 400 m upstream from its confluence with the Río Oyacachi.	0
102	Río Quijos, 100 m from the bridge, ca. 4 km west of the Baeza gas station.	8 (two pans)

The distribution of alluvial gold indicates that there is possibly more than one primary source of gold in the area.



3.1.2 Copper

Copper mineralization was identified in the following blocks from west to east (see map):

- (a) Trace of bornite in the blue quartz and garnet granoblastic rock.
- (b) Río Chalpi: block of grey phyllite with small mineralization of azurite/gypsum.
- (c) Río Chalpi: small blocks of coal with veinlets (5 mm) of calcite/graphite with pyrite and chalcopyrite.
- (d) Río Oyacachi: several blocks from the Río Cedro pluton of granitoid or quartz-monzonitic type, foliated or non-foliated, have small and disseminated chalcopyrite-bornite-malachite mineralization.
- (e) Along the path between the Río Cedro pluton and the Río Santa María: metalava (greenstone) blocks with small chalcopyrite-malachite mineralization associated with a quartz vein.
- (f) Río Santa María: small pockets of chalcopyrite-pyrite in quartz veins within epidote rock blocks up to 10×4×2 m in size.

3.1.1 Iron

Magnetite exists in the skarn blocks of the Río Chalpi/Oyacachi and the Río Quijos.

3.2 Occurrences of non-metallic minerals

3.2.1 Asbestos

In the Río Chalpi there are small blocks of a mineralized (pyrite) quartzite? with traces of a white-grey asbestiform mineral, but without economic interest.

3.2.2 Hot springs

In front of Oyacachi Nuevo, on the opposite side of the Río Oyacachi, there is a thermal water source, which the inhabitants use as a pool.

3.2.3 Carbonate

There are blocks of impure marble (Chalpi and Quijos rivers) and occurrences of travertine, but none of economic interest.

3.2.4 Graphite and coal

The graphitic schists do not have enrichment zones.

In the Río Chalpi there are small blocks of massive coal, probably sedimentary, with graphite formed by movement zones.

3.2.5 Ornamental stone

There are several lithologies which can be considered for the polished stone industry. The most attractive are those of blue quartz: the metagranite and, especially, the granoblastic rock with blue quartz and strong pink-coloured garnet.



3.3 Mineral potential

3.3.1 Skarn fields and epidotic rocks

Boulders of “mafic” type skarn rocks, similar to those from the El Placer skarnfield in the Llanganates (Litherland, 1988), were found in two sectors.

- (a) In the Río Chalpi and downstream in the Río Oyacachi, there are small and scarce “mafic” type skarn blocks with an epidote-garnet-magnetite-pyroxene-amphibole? composition. These blocks do not carry heavy sulphide mineralization.
- (b) In the Río Quijos upstream from the confluence of the Río Papallacta, there are large “mafic” skarn boulders up to 5×3×3 m in size. Also in the same river, there are blocks of serpentinite, Tres Lagunas type metagranite, and dark impure marbles. The skarn blocks contain fine-to-medium grained pink garnetiferous sectors divided by green zones rich in epidote and dark zones rich in amphibole and magnetite, all intruded by calcite and quartz veins with sulphides. Some sectors of the garnetiferous rock are medium-grained and consist of almost pure garnet. They are similar to the Nambija skarns, but they lack the adularia veinlets, which are the ones that carry the gold in Nambija.

It is clear that by following the drainage basins of the Chalpi and Quijos rivers, two new skarnfields with possible gold potential will be found.

There are rocks rich in epidote associated with the skarn blocks. However, in the Santa María, San Juan Chico, Cosanga, and Papallacta rivers, there are epidote rock blocks without indications of skarn blocks.

In the Santa María and San Juan Chico rivers, the epidote-rich blocks are associated with local green metalavas and metatuffs, and it is possible they are the product of contact metasomatism from the Río Cedro pluton. The blocks are up to 10×4×2 m in size and are generally mineralized with sulphides.

3.3.2 Gold sources

The distribution of panned gold (see 3.1.1) indicates that, probably, more than one source of gold exists. But this does not necessarily imply that these sources are the skarns to the west and hydrothermal gold related to the Río Cedro pluton further east, i.e., related to the Subandean gold belt (Litherland, 1988). There are other possibilities, e.g., Cenozoic volcanism, serpentinites, and mineralized carbonaceous rocks.

3.3.3 Recommendations

Depending on the gold analysis, this project has provisional plans to return upstream to the Quijos and Chalpi (of Oyacachi) rivers to locate new skarnfields and verify their mineral potential and their geological/tectonic environment. It is worth noting that the El Placer skarnfield (Litherland, 1988) is in the form of a subhorizontal tectonic thrust.

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Dr. Martin Litherland

Ing. Miguel Pozo

CORDILLERA REAL PROJECT



No. 0580

QUITO, JANUARY 17, 1989

TO : GERENTE TÉCNICO

FROM : DR. MARTIN LITHERLAND and ING. MIGUEL POZO T.

SUBJECT : Technical Report of the traverse between Laguna Micacocha and the town of Cosanga, from November 29 to December 14, 1988

1. INTRODUCTION

1.1 Project context

The technical collaboration project between the governments of Ecuador and Great Britain involves the collection of field data to understand the geology of the Cordillera Real, aimed at establishing a model of its formation processes, as well as its relationship with the environments that govern potential mineral resources for future local work concerning the Instituto Ecuatoriano de Minería.

1.2 Objectives

The commission, which is the subject of this technical report, was carried out from November 29 to December 14, 1988; its objective was to conduct a geological research traverse from Laguna Micacocha, along the Río Antisana, the headwaters of the Río Cosanga, and downstream from it, to the town of Cosanga in the Amazon region, Napo province.

The geological information collected during this traverse included: structural data, rock sampling for subsequent petrographic analysis, and the collection of heavy and fluvial sediments in areas of potential economic interest, all aimed at establishing possible lithological correlations with data obtained from previous geotraverses in the Cordillera Real.

1.3 Geography and hydrography

The area is characterized by high topographic features and deep valleys, along which rapid rivers such as the Antisana and Cosanga drain; the latter is joined by the Aliso, which finally flows into the Quijos.

Due to the lack of geographic names on the topographic sheets used within the research area, some names in the Quichua language have been suggested to provide elements for geological references.

Within this framework, we have the following tributaries of the Río Cosanga: Shingashcahuaicu, Lorohuaicu, Parahuaicu, and Ishcaiyacu.

Additionally, the following geographic features: Osourco and Ñancarourco, Chiriurco, Urcucocha, Shingashcaurco, and Lorosacha, with altitudes around 4200 mamsl, from where the topography begins a continuous and sometimes abrupt descent toward the Sub-Andean region, within the research area, to altitudinal levels around 2000 mamsl.

1.4 Climate and vegetation

The mentioned topographic conditions have an impact on the climate of the region, which varies from cold and frigid in the high areas to temperate in the low areas; in the high areas, temperatures can vary from zero to 11.9 degrees Celsius, which in turn correspond to altitudinal belts between 3000 and 4000, or more, mamsl (Naranjo, P. 1981).

In the second case, however, the external flank condition of the Cordillera Real is considered, where a very humid variety is found, with temperatures between 12 and 17.9 degrees Celsius, corresponding to the altitudinal belt between 1000 and 3000 mamsl.

The rainiest season in the eastern zone of Ecuador, which includes the study area, corresponds to the months ranging from April to October, with higher peaks in the months of May, July, and October. From November to March, the amount of rainfall is lower. In fact, this is the rainiest and most humid region of the country, where more than 250 days of rain per year are recorded.

1.5 Access

It is suggested that, during the preparations for future commissions, permission be requested to cross the Hacienda Pinantura at the following address:

Sr. Carlos Delgado
Calle La Cumbre No. 217 y Quiteño Libre
Quito

From the town of Píntag, follow the road that leads to the Hacienda Pinantura and from there to the Laguna Micacocha; if the weather is good and the terrain in this sector is not very swampy, it is possible to follow downstream of the Río Antisana for a distance of approximately 6 km.



From this point to the town of Cosanga, the traverse can be done on foot; first, following the course of the Río Antisana. Then crossing the páramos of Osourco, Ñancaroyacu, and Chiriyacu until reaching the source of the Río Cosanga; then, the traverse continues along the course of this river to the town of Cosanga.

Another alternative, in the final stage of the traverse, consists of following a trail from the sector called Las Caucheras to the start of the drivable road that leads to the aforementioned town.

1.6 Work methodology

The following topographic sheets at a scale of 1:50000, published by the Instituto Geográfico Militar, were used.

- “Cosanga”, June 1988.
- “Laguna de Micacocha”, January 1983.

And the aerial photographs, LEARJET; PROYECTO CARTA NACIONAL:

10731, 80.02.11	8865, 79.01.18
8883, 79.01.18	8867, 79.01.18
8866, 79.01.18	8855, 79.01.18

Additionally, 50 rock samples, 5 heavy sediment samples, and 3 fluvial samples were collected.

Finally, as collective equipment, four tents and one mountaineering rope were used.

1.7 Previous works

Bermúdez R. (1988) Technical report of the commission carried out at the Río Antisana, headwaters of the Río Cosanga, from January 18 to 28 of the current year (unpublished report), Instituto Ecuatoriano de Minería, Quito.

1.8 Assigned personnel

Dr. Martin Litherland	(British Mission)
Ing. Miguel Pozo	
Sr. Manuel Céleri	(Driller)
Sr. César Vinuesa	(Driver)

As support personnel, the following labourers were hired from the San Alfonso community, in the vicinity of the town of Píntag, province of Pichincha:

Carlos Catagnia, Tobías Morales, Pedro Bravo, Angel Chauca, Jorge Ordóñez, René Ordóñez, Rosendo Flores, and Segundo Flores.

1.9 Transport

The Jeep Land Rover plate AT-0068, belonging to the British Mission, was used from Quito to Laguna Micacocha and later from Cosanga to Quito.

1.11 Detailed activities

Month	Day	Traverse
November	29 y 30	Approach to Laguna Micacocha and Río Antisana
	01 y 02	Approach along the Río Antisana
	03	Approach to the headwaters of the Río Cosanga
December	04 al 13	Traverse along the Río Cosanga to the site called Las Caucheras
	14	Return to Quito

During the traverse, structural data, rock samples, heavy and fluvial sediments were taken, the details of which are presented in the chapter referring to geology.

2. GEOLOGY

2.1 Introduction

The Antisana-Cosanga section comprises a páramo-type landscape up to the Sub-Andean front. It is the area of the Cordillera Real where the páramos extend further east, which facilitates studies of metamorphic rocks.

In terms of structure, undoubtedly, for the first time an Alpine-Himalayan type profile has been detected, and thus, the Antisana-Cosanga section will be very important for the geology of Ecuador and the Andes in general, for being the site of the first evidence of classic continental collision structures.

2.2 Granitoid rocks

2.2.1 Tres Lagunas type metagranite

To the west of the traverse, orthogneisses outcrop, and in certain places, with blue quartz. To the west of the Quebrada Soledad, they are medium to coarse-grained with a tectonic foliation. To the east, textures range from “eyes” (augen) to mylonitic predominate. Further east, within the skarn division, there are some tectonic veins of metagranite (of this type) within a small, geologically very complicated area.

The correlation with the Tres Lagunas granite suite is based on the petrological aspect (presence of blue quartz and muscovite) and its location to the west in the central belt of the metamorphic complex.



2.2.2 Abitagua granite

This batholith is located at the eastern limit of the section and was not observed in the field.

2.2.3 Pegmatites

In the Quebrada Chiriyacu, there are boulders of orthogneiss with folded pegmatitic veins.

2.2.4 Feldspathic rocks

In the area around Laguna Urcucocha, there are small zones of metaplutonic rocks with abundant feldspar, “Azafrán” type.

Through the Sub-Andean zone, there is a medium-grained feldspathic intrusion.

2.2.5 Microgranites

In the Quebrada Chiriyacu, there are boulders of undeformed microgranite/aplite with brown weathering spots.

2.3 Basic rocks

2.3.1 Metavolcanics

Greenstones of meta-andesitic or metabasaltic composition predominate in the Sub-Andean zone and in the upper reaches of the Río Cosanga. They have a massive or schistose appearance of greenschist facies and are intercalated with graphitic schists and dark siliceous metavolcaniclastic rocks. According to boulders found further east, the greenstone belt mostly comprises meta-agglomerates.

2.3.2 Metadolerites

Toward the west, there is an amphibolite band nearly 80 m thick, tectonically intercalated with the Tres Lagunas type metagranite, which could represent a pre/syn-tectonic doleritic intrusion.

2.3.3 Diorites

On the eastern side of Laguna Urcucocha, there are small areas where strongly epidotized diorite outcrops, which could correspond to the Azafrán complex.

2.3.4 Epidote rocks of “skarn” type

Rocks of this class outcrop in a synform, tectonically intercalated with quartzites and quartzose schists (see profile). They are pale green rocks, massive to gneissic, with epidote, quartz, and amphibole. The more massive types without foliation have a surface called “elephant skin”. The presence of garnet or magnetite was not determined; however, identical rocks outcrop in the El Placer skarnfield (Litherland, 1988). For this reason, the epidote rocks found in the Micacocha-Cosanga traverse are correlated with those of the Llanganates skarn belt.



In an outcrop to the west of Laguna Urcucocha, it is noted that the protolith of the rocks found there is a green metavolcanic rock with calcite veins; the epidotization process is variable and prior to the subhorizontal deformation, which has given rise to a breccia of epidotized zones, non-epidotized zones, and calcite veins.

2.4 Ultrabasic rocks

2.4.1 Serpentinities

The Micacocha-Cosanga section determined the following three serpentinite belts through the Cordillera Real:

(a) The Quebrada Soledad serpentinite: along the western flank of the Quebrada Soledad valley, there are serpentinite outcrops (Bermúdez, 1988) traceable in a line.

The outcrops appear as rounded protrusions that stand out on the surface due to the contrast in resistance between the serpentinite and the host rocks. In the studied outcrop, there were two rock bands, one 8 m thick and one 2 m thick, separated by 20 m without outcrops, which could also be serpentinite, with a total thickness of 30 m. However, these bands do not continue along the entire strike of the valley; in the creek to the north of the studied outcrop, there is no serpentinite.

The rock is massive, dark, mottled with green zones and with small brown weathering spots of ferruginous material.

(b) The Urcucocha serpentinite was not observed in outcrops, only in boulders in the Quebrada Chiriyacu and in the headwaters of the Río Cosanga. Thus, there are boulders coming from each flank of the Urcucocha synform (see profile). Some blocks are of a massive type, but many are highly foliated, of a green-grey colour laminated with brown. There is also a small number of sulphides in these latter samples and the presence of “micaceous” porphyroblasts (clinochlore?).

The blocks are no larger than 1×1×1 m and thus the serpentinite band is perhaps thin; its location is probably between the semipelites and the schists (see profile).

(c) The Sub-Andean serpentinite is another serpentinite band identified by boulders. In the Río Cosanga, downstream, the small serpentinite blocks from Urcucocha disappear. Then, in the Sub-Andean zone, large blocks appear with sizes up to 6×5×5 m, which suggest the presence of a new band, whose location is indicated approximately in the profile. The rock is massive, like the one found in the Quebrada Soledad.

The serpentinite blocks near Baeza (Colony and Sinclair, 1932; Litherland et al., 1986) probably represent the northward continuation of the Sub-Andean serpentinite belt.



2.4.2 Actinolite rock

There are boulders of asbestiform actinolite in Quebrada Chiriyacu and they are probably related to the Urcucocha serpentinite.

2.4.3 Ultramafic schist

Small boulders of actinolite-tremolite schist were observed in the Río Cosanga along with dolomite blocks (see 2.5.8).

2.5 Metasedimentary rocks

2.5.1 Quartzites

Pale, fine- to medium-grained quartzites of continental derivation outcrop in the core of the Urcucocha synform where they are tectonically intercalated with epidote rocks. They are tectonically banded and associated with quartzose schists. Some sectors develop a dark porphyroblastic mineral, probably chloritoid.

There is a band of fine quartzite intercalated, perhaps tectonically, with the metagranites to the east of Quebrada Soledad.

Orthoquartzites also form part of the semipelitic sequences (see 2.5.2).

Quartz schists also outcrop in the Sub-Andean zone.

Quartzite boulders? with fuchsite were found in Quebrada Ñancaroyacu.

2.5.2 Semipelites

The most extensive zone of semipelites outcrops on both flanks of the Río Cosanga canyon. They are fine, pale, banded quartzites with black graphitic phyllites. The unit as a whole is similar to those of the Loja semipelitic phyllitic division (Litherland, 1988).

Structurally, below the serpentinite of Quebrada Soledad, there is a sequence of graphitic phyllites interlaminated with metasilstones and intercalated with orthoquartzites.

2.5.3 Pelitic schists

Metapelites with muscovite and chlorite dominate the structural sequences below the epidote rocks and below the dolomite. In the Sub-Andean zone, there are blocks of quartz schists, chloritoid, and dolomite.

2.5.4 Graphitic schists

Phyllites and graphitic schists are prominent in several sections, associated with greenstones, quartzites, or pelitic schists.

2.5.5 Metawackes and volcanoclastics

Boulders of grey, medium-grained metawackes were found in the Río Cosanga above the Sub-Andean front; this lithology is probably associated with the greenstones. Similar blocks come from the hills located to the east of the Sub-Andean front.

In the Sub-Andean zone, there are also black-grey siliceous phyllites with deformed volcanoclasts.

2.5.6 Cherts

In the Sub-Andean zone, there are fine, pale, banded siliceous rocks, which could be of the chert type.

2.5.7 Marble

In the Sub-Andean zone, there are pale, medium-grained marble blocks, apparently unrelated to the Napo Formation and associated with blocks of deformed shaly limestones.

2.5.8 Dolomite

At the structural base of the Río Cosanga semipelites, there are boulders of a massive rock that has a brown weathering surface, carbonate type. However, the rock does not react with acid. Other blocks contain green muscovite (fuchsite). In thin section, the rock is dominated by carbonate, probably dolomite, with quartz and fuchsite as impurities.

2.6 Cretaceous Formations

In the Sub-Andean zone, downstream in the Río Cosanga, there are outcrops of limestones and black shales of the Napo Formation type. There are also blocks of pale orthoquartzite and red sandstone, which resemble those of the Hollín and Tena Formations respectively.

2.7 Structural Geology

2.7.1 Tectonic history

The section can be divided into three structural domains:

- (a) The domain west of the Sub-Andean front, where tectonic foliations are gentle.
- (b) The Sub-Andean domain, where tectonic foliations are subvertical.
- (c) Further east of the Río Cosanga fault, where the Cretaceous Formations are not deformed.

To the west of the Sub-Andean front, the structural history has three phases: D1-D3.

D1 is recognized by the cleavage (schistosity S1) and many quartz veins subparallel to the bedding, folded by D2.

D2 is associated with schistosity S2, which is represented by the gentle-dipping foliation and coincides with the axial plane of recumbent folds with an Andean strike; it also forms the mylonitic foliation in the metagranite.



D₃ is responsible for monoformal folds, as well as the Urcucocha synform (see profile) and the steep westward-dipping crenulation cleavage. The axial plane of D₃ has an Andean strike.

Only in the Laguna Urcucocha sector does the geology become complicated; there, the metaplutonic rocks have subvertical tectonic foliations with an east-west strike. Subhorizontal folds, with the same strike, affect the metapelitic rocks.

In the Sub-Andean zone, there is S₂ superimposed on S₁ in the pre-Cretaceous rocks. D₃ is manifested by the first cleavage in the Cretaceous Formations, which gives them a weak tectonic foliation with a steep dip, and an axial plane to minor folds with a steep plunge.

To the east of the Río Cosanga fault, it appears that the Napo Formation has no cleavage and is not deformed.

2.7.2 A tectonic stratigraphy

Although recumbent folds with wavelengths of up to 20 m had been seen, most contacts between lithological units are probably tectonic and related to overthrust faults. This interpretation is supported by the mylonitic foliations and the juxtaposition of lithologies from different formation environments.

Thus, in the geological profile (see), a tectonic stratigraphy can be distinguished in the Cordillera Real, based on the superposition of thrust “sheets”. In the Sub-Andean zone, these “sheets” are affected by Tertiary thrusts, which also affect the Cretaceous Formations. It is possible that this Tertiary event is equivalent to D₃ toward the west.

3. ECONOMIC GEOLOGY

3.1 Occurrences of metallic minerals

3.1.1 Gold

Gold was panned upstream in the Río Cosanga (see map). Two pannings yielded four angular gold specks. Upstream, the geology comprises schists, quartzites, epidote rocks (skarn), and serpentinite.

3.1.2 Chromium

Fuchsite (chrome muscovite) is present in blocks of impure dolomite and impure quartzite, but without economic interest.

3.1.3 Molybdenum

Disseminated mineralization of molybdenite type (?), on a metric scale epidotic rock wall, is characteristic in a sector west of Laguna Urcucocha.

3.2 Occurrences of non-metallic minerals

3.2.1 Asbestos

There are small boulders of asbestiform actinolite in Quebrada Chiriyacu, and small veins (1 cm) of antigorite asbestos in serpentinite blocks upstream in the Río Cosanga. However, there is no economic interest.

3.2.2 Coal

Graphitic schists/phyllites outcrop in various parts of the section, but there is no economic enrichment.

Small blocks of coal were seen in the Río Cosanga downstream, probably from the Napo Formation.

3.2.3 Carbonate

Marble blocks from the sub-Andean basement and limestone outcrops of the Napo Formation.

Large blocks of impure dolomite were found in the Río Cosanga.

Travertine deposits up to 1 m thick (see map).

3.2.4 Talc

In small boulders of talcose schist in Quebrada Ñancaroyacu.

3.3 Mineral potential

The analysis of the molybdenite (?) is expected before considering the metallic potential of the area.

However, almost certainly the epidote rock represents the Llanganates skarn belt (Litherland, 1988), which is traceable from the Río Mulatos to Oyacachi (Litherland and Pozo, 1988) over a distance of approximately 100 km.

The Llanganates skarn belt outcrops in isolated skarnfields, due to the erosion of a skarn thrust sheet at high topographic levels. So far, the skarns have not given good economic prospects, but the layer is so thick (approximately 100 m or more) that it forms true mountains for metallic prospecting.



4. REFERENCES

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Dr. Martin Litherland

Ing. Miguel Pozo

CORDILLERA REAL PROJECT

No. 4919

QUITO, AUGUST 11, 1988

TO : GERENTE TÉCNICO

FROM : ING. MIGUEL POZO – CORDILLERA REAL PROJECT

SUBJECT : Technical report of the commission to the provinces of Azuay, Cañar, and Chimborazo, from May 22 to June 15, 1988.

1. INTRODUCTION

1.1 Project context

The Cordillera Real Project contemplates the collection of field data to understand the geology of the Cordillera Real and, in this way, attempt to establish a model of its formation mechanisms, as well as identify a possible relationship with mineral potential.

1.2 Objectives

The commission carried out during the days of May 22 to June 15, 1988, in the provinces of Azuay, Cañar, and Chimborazo had the purpose of studying the “Tampanchi ultramafic complex” in greater detail, with a view to defining its contacts as much as possible and establishing its stratigraphic relationship with the Alao-Paute division.

Another objective was to recognize its probable presence toward the north of Tampanchi, in the same province of Cañar and also in Chimborazo, in the vicinity of the Magtayán and Cubillín lakes.

Finally, it sought to find new evidence aimed at defining the structural relationships between the Alao-Paute division and the Yunguilla Formation.

1.3 Assigned personnel

Ing. Miguel Pozo
Sr. Víctor Vega

1.4 Geography and hydrography

The studied areas are located in the provinces of Azuay, Cañar, and Chimborazo. The relief is very irregular with long and high drainage divides, such as Cerro El Huangü, Huagra Loma, Loma Mesapata, Cerro Tamiamanga, Cerro del Gafel, Cerro Yanguán, and Cerro Huiñahuarta, among others, and deep valleys along which torrential rivers flow, such as the Juval, Mazar, Ramada, and Pindilig, which empty into the Río Paute.



1.5 Climate and vegetation

Due to the very marked changes in topography, several climates are found, from the Andean cold to the temperate, which influence the flora and fauna of the region. These characteristics are utilized by the inhabitants of the region for the sowing of products such as: corn, broad beans, barley, wheat, etc.

It should be noted that native forest was found in the páramo zone, which is being deforested indiscriminately by the inhabitants, with a probable impact on the ecological balance of the region.

1.6 Roadways

From Azogues, a drivable road with a paved surface continues, connecting the towns of Taday, Pindilig, Shoray, and Buenos Aires to the north; Violán, Tampanchi, Guarainac, Tomebamba, Huachapata, Paute, and Cuenca to the east and south.

High zones can be reached following summer roads and/or bridle paths, such as the case of the Huangra Hamlet.

1.7 Socio-economic aspect

The population is organized into communities headed by a board of directors; among the main activities carried out in the area are agriculture, livestock farming, fishing, and sporadically, gold placer mining. The making of straw hats is another characteristic activity, along with the domestic textile industry.

Recently, the laying of high-voltage power lines has represented another source of income, although for a small number of people.

1.8 Previous works

- Litherland M., Aspden J. A., Bermúdez R., Viteri F. (1988) Segundo Informe Anual, Proyecto de Investigación Geológica Cordillera Real, British Geological Survey, UK, Instituto Ecuatoriano de Minería.
- DGGM (1972-1973) Hoja geológica “Cañar”, escala 1:100000, Quito.
- DGGM (1972-1973) Hoja geológica “Alausí”, escala 1:100000, Quito.

1.9 Work methodology and itinerary

The following topographic sheets at 1:50000 scale, published by the IGM, were used:

“Cola de San Pablo”, 1969
“Huangra”, 1968

“Guachapala”, 1976
“Totoras”, 1968

Aerial photographs 11351 to 11354, R-58, LEARJET, from 26-8-80, approx. scale 1:60000.

For the best success of the commission, during the 22nd to the 27th, a general reconnaissance of representative points of the region was carried out, which was composed of the following personnel:

Dr. Martin Clarke
Dr. John Aspden

Ing. Francisco Viteri
Ing. Miguel Pozo

Sr. Manuel Céleri
Sr. Víctor Vega

During this phase, traverses were made to representative outcrops of the Maguazo turbidites, Alao-Paute metavolcanics, Yunguilla phyllites; and Tampanchi ultramafics.

Regarding the rest of the commission, rock sampling was carried out at 104 points and 8 heavy sediment samples were collected; another activity was the measurement of structures such as: bedding, foliations, and lineaments.

Sites where it was not possible to enter by vehicle were accessed with the help of pack animals and their respective muleteers. In addition, the help of day labourers was always available.

The names given to the rocks in this report are tentative. The subsequent preparation of thin sections, their study, and discussion will allow for definitive conclusions that will be released in the next annual report.

The itinerary was as follows:

Month	Day	Traverse
May	28	Taday-Huarainac
	29	Violán-Huarainac
	30	Quebrada Tasqui, downstream toward the Río Paute, return along the right bank of Río Pindilig
	31	Pindilig route, Río Dudas upstream, Asunción Dudas
June	01	Pindilig, Cerro Yanguán and through Quebrada Ingapata to the town of Shoray
	02	Buenos Aires-Quebrada Llavircay
	03	Buenos Aires-Huangra
	04	Huangra-Río Juval (downstream)
	05	Huangra, Río Juval (upstream)
	06	Huangra-Buenos Aires-Pindilig
	07	Quebrada Unig traverse, Desincho, Loma Ventanilla, Shall town, Cerro Yanguán, Pindilig
	08	Pindilig, Riobamba
	09	Riobamba-Palmira, Osogochi, Laguna Magtayán (difficulties with indigenous communities and bad weather; return is undertaken), Chunchi
	10	Chunchi, Quebrada de Mangán (work is restarted), Pindilig
	11	Pindilig, Huarainac, Quebrada Las Juntas
	12	Loma Picotapata, Quebrada Tansaray, Río Cachi Corral upstream
	13	Quebrada Asuncion Dudas upstream
	14	Visit to the Pilzhum mine, Azogues
	15	Return to Quito



2. GEOMORPHOLOGY

The geomorphology is strongly dominated by the effects of glacial and fluvial erosion, in the upper and lower sections respectively.

The presence of widely distributed metamorphic rocks and the erosive action of rivers have formed deep V-shaped valleys, whose divides are represented by elongated and very steep ridges, several kilometres in length.

In areas consisting of granitic rocks, the topography tends to adopt rounded forms.

3. GEOLOGY

In accordance with the purpose of the commission, emphasis was placed on the units specified below; however, other accessory units were found, which could have some significance in the global context of the regional geological process.

3.1 The Tampanchi Mafic-Igneous Complex

3.1.1 Project context

According to the Second Annual Report of the Cordillera Real Project, it is stated that this is probably the first stratified mafic-igneous complex to be recognized in Ecuador.

3.1.2 Location

An attempt was made to define the extent of the outcrop, for which several traverses were carried out. Rocks of this complex were identified in the Tampanchi area (Photo 1) and along the Quebrada Tasqui; towards the south, along the road to Huarainac, blocks corresponding to similar rocks were found.

A traverse along the road from Huarainac towards Tomebamba demonstrates the influence of the complex in question as far as the Quebrada Dacñales (615-039), in whose bed it was common to find boulders and blocks of mafic rocks; this did not occur in the Quebrada Las Juntas (605-015), which tends to delimit the extension of the mentioned complex towards the south.

To the north, on the left bank of the Río Pindilig, from the Desincho site (620-094) to Loma Ventanilla (645-099), basic intrusive rocks (CRMP-437-ABC) were found.

From Loma Ventanilla to Shall (6317-100) and then uphill toward Cerro Yanguán, only sporadic fallen blocks of basalt (CRMP-440) were identified; this occurrence also took place at the Hacienda Ingapata sites (644-133) and from this site 1 km to the NW, on the right bank of the Río Mazar. It is clarified that in these last localities, no indication of basic rocks such as those in Tampanchi was seen.

It should be noted that in this commission it was not possible to find spectacular “sedimentary” structures of the Alaskan Pipe type (see Irvine, T. N., 1974; Murray, C., 1972), at a decametric scale, which include cross-bedding, graded bedding, etc. However, it was possible to frequently observe textural features that suggest a certain mineral segregation, which has produced in the rocks in question a vein-like external appearance (Photos 2-3), or a sedimentary appearance.

In the traverse carried out to the Río Juval valley (632-298), attention was paid to the possible presence of ultramafic rocks correlatable to those of the Tampanchi complex.

It is important to point out that, at least in this investigated region, no evidence of any kind was detected regarding the “Tampanchi mafic-igneous complex”, which tends to undermine the idea of its possible presence in an elongated N-S strip.

Geomorphologically, it is very likely that these rocks extend towards the right bank of the Río Paute, in the vicinity of the Pahuancay site (655-104) and/or the divide of the quebradas Chontas and Pahuancay; on this occasion, it was not possible to investigate these sites.

In conclusion, as a progress report of the study, an approximation can be made, tending to delimit the extension of the Tampanchi mafic-igneous complex in the following way:

Tentative delimitation of the “Tampanchi mafic-igneous complex”.

- (a) To the North: Left bank of the Río Pindilig, in the vicinity of the Desincho and Loma Ventanilla sites.
- (b) To the East: The Río Paute
- (c) To the South: Quebrada Dacñales
- (d) To the West: From the Desincho site, Tampanchi, upstream from the Quebrada Tasqui, the Huiñahuarta and Gafel hills

According to this preliminary delimitation, the approximate area in which this complex has been detected is approximately 18 km².

3.1.3 Lithology

It is composed of pyroxenites, hornblendites, gabbros, basalts, dunites (?) and serpentinites (CRMP-358, 360-ABC, 370-1-2, 374-AB, 377 and 379 to 387-AB).

3.1.4 Stratigraphic relationships

The rocks of the “Tampanchi mafic-igneous complex” are not found deformed as is the case with the Alao-Paute division; furthermore, they seem to correspond to a late stage of magmatism, for which, stratigraphically, the “Tampanchi mafic-igneous complex” would be above the Alao-Paute division and at least below the Tarqui Formation.



3.2 Llavircay intrusive

3.2.1 Location

During the traverse carried out along about 3 km of the Llavircay River, several “in situ” outcrops of granodiorite (CRMP-411, 412, 417) were found in its bed. The same was found on the road from Buenos Aires, along the right bank of the Llavircay River (637-181).

3.2.2 Lithology

Porphyritic felsic rock, with quartz, plagioclase, and hornblende: granodiorite, CRMP-411, 412, 417.

3.2.3 Stratigraphic relationships

Although there is no field evidence, it is interpreted that this unit is cutting through the rocks of the Alao-Paute division; its relationship with the Tampanchi ultramafic complex is unknown, although taking into account the magmatic differentiation processes, the Llavircay intrusive could be stratigraphically above the mentioned complex, and both corresponding to a late episode of magmatism.

3.3 Llavircay phyllites (metabasalts?)

3.3.1 Location

Rocks of this type were located in the Quebrada Llavircay (631-201), also on the right bank of the Quebrada San Vicente 2 (provisional name), in its first 50 to 80 m, upstream.

3.3.2 Lithology

Dark grey rocks, with cleavage and the appearance of basalts (CRMP-410, 413B, 414, 416).

3.3.3 Stratigraphic relationships

Unknown, although their incipient cleavage denotes a bit of tectonism, for which their deposition would have taken place after the Yunguilla Formation and before the displacement of the “Tampanchi mafic-igneous complex”/Llavircay intrusives suite.

3.4 Yunguilla Formation

3.4.1 Location

There is an outcrop on the left bank of the Río Ramada and downstream, forming the divide between this river and the Cachicorral, where rocks are presented in an antiform, whose southern flank has been eroded by the Río Ramada. Apparently Duda Loma (525-067) would be composed of these rocks on the bank of the Río Ramada; about 20 m to the east of the outcrop in question, blocks of green rock were found.

On the right bank of the Quebrada Yunguilla (537-095), small outcrops were observed, and blocks of the Yunguilla Formation exclusively also outcropped; it cannot be determined whether they were transported or if they belong to “in situ” rock, covered by recent deposits.

The geomorphological difference on both banks of the Quebrada Tansaray, which downstream becomes the Río Ramada, denotes the existence of two different lithologies, with evidence of Yunguilla and Alao-Paute.

In the vicinity of the Joaquirín site (545-129), in a westward direction, the presence of the Yunguilla Formation ends and the appearance of green rock with opal(?) vesicles and pyroxenes is noted again. Up to about 1 km to the NW, on the right bank of the Quebrada Deshiñán, both types of rocks are present in the form of fallen blocks. On the left bank of this creek, on the recently opened road for access to the high-voltage towers, an “in situ”(?) block of green rock was found with foliation dipping toward the east and also with jointing.

Up to Joaquirín (534-101) it was not possible to find lithological evidence of any kind, due to the presence of páramo coverage; however, along the left bank of the Quebrada Yunguilla, sporadic “in situ” outcrops were identified, corresponding to schists and green rocks (CRMP-456).

Toward the N of the study area, on the northern flanks of Loma Huacarrumi (555-103) and on the left bank of the Quebrada Asunción Dudas (provisional name), a very fractured outcrop and fallen blocks of Yunguilla were found. The same was found upstream in two-thirds of its upper course.

In the lower third of its right bank, following toward the SE and along the right bank of the Río Dudas, by the current road for the high-voltage line installation, subrounded blocks between 0.80 and 2 m in diameter were found scattered, corresponding to a green andesite (CRMP-457), a condition that persisted until the Quebrada Playadudas (565-114, provisional name).

Toward the SE of this creek, at about 150 m, an outcropping block (“in situ”?) of consolidated breccia appeared, consisting of Yunguilla blocks (Photo 6, CRMP-458) in a consolidated matrix; from then on, rocks of the Yunguilla Formation and green rock boulders were found.

In conclusion, “in situ” rocks of the Yunguilla Formation are found in the lower part, at least topographically, and are visible in Asunción Dudas and in the creek of the same name; however, although no “in situ” outcrops of green rocks were found, the presence of blocks of this type suggests the presence of rocks from the Alao-Paute division further uphill.



3.4.2 Lithology

This Formation is composed of an alternation of fine-grained argillites, shales, and yellowish-brown to dark brown tuffs; stratification is present, sometimes with signs of tectonism (S₁) and deformation (D₁).

3.4.3 Stratigraphic relationships

Characteristic differences exist between the Yunguilla Formation and the Alao-Paute division; thus, while the Alao-Paute division is highly sheared, with at least two tectonic cleavages (S₁, S₂) and several deformations (at least D₁ and D₂), the Yunguilla Formation has apparently undergone only one deformation (D₁) and one tectonic cleavage stage (S₁), so its rocks do not present the degree of shearing found in the Alao-Paute division.

For this reason, it is logical to assume that the Alao-Paute division formed first and underwent several stages of deformation and shearing; subsequently, the Yunguilla Formation originated, and then both lithological units underwent the final stage of deformation together.

In conclusion, according to what has been stated, the Yunguilla Formation overlies the Alao-Paute division.

3.4.4 Discussion

The location of the Alao-Paute division on top of the Yunguilla Formation could signify the presence of an enormous folding event that has brought these rocks to their current stratigraphic position.

The presence of breccia with constituent blocks of the Yunguilla Formation could have some significance in that process.

New outcrops tend to establish that the possible contact of the Yunguilla Formation is located further to the east, in relation to the transitional dotted line placed on the “Cañar” geological sheet, scale 1:100000, DGGM, 1972-1973.

3.5 Alao-Paute division

3.5.1 Location

They constitute widely distributed rocks in the study area. To explain their presence, the area will be divided into the following sectors: South, South-central, North-central, and North.

3.5.1a South area

C Comprised from the right bank of the Ramada/Macas/Pindilig and Paute rivers, toward the south.

The green rocks of the Alao-Paute division are visible along the road leading to Huarainac (636-058), at least from the vicinity of Loma Picotapata (Photo 5, 535-053). Thus, on the left bank of the Quebrada de Mangán (513-059), about 400 m downstream from its confluence with the Quebrada Gulag, an outcrop with greyish siliceous rocks probably belonging to this division (CRMP-443) is present.

In the Capulípamba area (545-069), greenish-grey rock boulders were observed in small streams, suggesting the presence of “in situ” rock further uphill. It is possible that blocks found near the hacienda San Juan, at point 541-074 on the right bank of the Río Ramada, could correspond to outcropping parts of “in situ” green rocks (Photo 4).

Near Rumirachi (580-083), outcrops with joints of greenish-grey rock (CRMP-363) were noted, which transitionally change toward the east from massive rocks of this type to foliated ones. Decametric and metric scale zones are notable in which massive strata are intercalated with other foliated ones.

There are occasions where it is possible to observe non-deformed blocks of green rock in the midst of foliation, in the manner of “eyes”; a case of this was visible on the road to Huarainac, on the left bank of the Quebrada Sircay (591-065). This tends to confirm that the green rocks and the schists correspond to a syn-tectonic (?) stage, but do not constitute two lithologies of diverse origin.

Continuing toward the east, phyllites were found as far as the Quebrada Concade (602-078); thereafter, and in a transitional form, basalts appear (CRMP-370), sometimes surrounded by foliated rocks probably from the Alao-Paute division and other times from the “Tampanchi mafic-igneous complex”.

In the Quebrada Tasqui (640-071) near the Río Paute, dark foliated rock again appears with sulphides, with a basaltic appearance (black phyllites?), with quartz alternations.

The entire area of Shahuarpica (645-076), La Balsa, and Palahuaicu consists of foliated rock.

3.5.1b South-central Area

Located between the Ramada-Macas-Pindilig and Paute rivers, toward the north; and the Quebrada Shuden (575-156) and the Río Mazar as far as the Río Paute.

In the vicinity of the Joariquín site (545-129), the contact between the Alao-Paute division to the east and the Yunguilla Formation to the west is probably found. From this point, up to about 1 km to the west, on the right bank of the Quebrada Deshiñán, both types of rocks are present in the form of fallen blocks.

On the left bank of this creek, on the recently opened road for access to the high-voltage towers, an outcropping block (541-136) was found, probably “in situ”, of jointed green rock with foliation dipping toward the east.

About 4 km toward the south, green rocks are present on the left bank of the Quebrada Yunguilla at Loma Joaquirín and toward the NE, on the right bank of the Quebrada Asunción Dudas (552-115).

Toward the east, these rocks make their appearance in the vicinity of Pindilig, in the surroundings of the Yanguán hill (600-124), and are also visible along the Quebrada Ingapata (635-130) and the right bank of the Río Mazar as far as the town of Shoray.



3.5.1c North-central Area, between the Shudan-Río Mazar and the Llavircay

In the area between the Mazar and Llavircay rivers, the presence of foliated rocks (CRMP-413) was detected through boulders.

On the right bank of the Quebrada Tamiamanga, at point 630-172, an outcrop exists where the rock appears to have been affected by strong tectonism (CRMP-410). Toward the north, on the right bank of the Llavircay River (630-201), rock with tectonic cleavage (CRMP-413-AB) is present.

Near this site, in the bed of the Llavircay River, boulders of green rocks, black phyllites, andesites, and porphyritic felsic rocks with pyroxenes and plagioclase in 2 to 6 mm crystals, and quartz, were found. Downstream, a dark rock with some cleavage (CRMP-414) was identified “in situ”.

During the traverse carried out to the Huangra Hamlet, from the Hacienda San Francisco site (619-163), small fallen blocks of grey and brown phyllites were found. On this occasion, it was not possible to identify good outcrops due to vegetation cover; however, it seems that this lithology extends to the Huangu Hill (625-232), where this evidence was also found. From this point toward the north, the lithology changes to massive and/or foliated green rocks.

At point 641-152, foliated rock (CRMP-420) was also found, correlatable with the Alao-Paute division.

3.5.1d North area

Located between the divide represented by the páramos of Cerro El Huangu (625-233) and toward the north the Río Juval.

In the páramos of Cerro El Huangu, sporadic rounded outcrops of massive and foliated greenish rock were observed, with dark-green crystals (CRMP-422); this condition, although there were no outcrops, was detectable in the Huangra Hamlet through fallen blocks.

In a traverse carried out along the right bank of the Río Juval, between points 640-286 and 676-249, it was possible to detect the presence of green schists, black phyllites, and quartzites. This evidence was found in the Daule (635-273), Huangra Yacu (650-270), San Carlos (645-263), Llohuaru (655-258), El Chorro (661-244), and Tuncay (670-244) creeks.

In the Quebrada Daule, a contact was found between grey phyllites on the left bank and massive green rock on the right, at least visible over a stretch of about 10 m (see CRMP-429 and 430, respectively).

3.5.2 Lithology

As has been mentioned repeatedly, this division is composed of grey, black, and yellow phyllites; as well as massive green rocks and schists of the same colour; finally, by quartzites.

3.5.3 Stratigraphic relationships

In the present commission it was not possible to find contacts between this division and the Yunguilla Formation. However, evidence found in several sites, such as at Hacienda San Juan (545-076), Loma Joaquirín (540-099), Quebrada Asunción Dudas (553-115) and in the vicinity of the town of the same name, suggest that there is a defined contact between the Alao-Paute division and the Yunguilla Formation, but not a transitional one as has been suggested; this statement is based on the lithological changes observed over relatively short distances: for example, 100 m in the Quebrada Asunción Dudas, and also on the differences in the degree of deformation and shearing, characteristic of each unit.

For the reasons stated in the stratigraphic relationships of the Yunguilla Formation (see 3.4.3), it would be overlying the Alao-Paute division.

3.6 Dudas volcanosedimentary rocks

3.6.1 Location

These rocks have been identified in several sites: one is found in an outcrop at the Asunción Dudas site toward the NW (551-129).

On the Taday-Pindilig road, after passing the bridge, on the left bank of the Río Ramada, there is a localized outcrop of rocks with a fine-granular appearance, probably correlatable with the rocks found on the Asunción Dudas road upstream from the Río Dudas; at point 559-079, near Taday, outcrops of this type of rocks were found (CRMP-446-A), where there is also a possibility of correlation.

3.6.2 Lithology

They are yellowish-brown rocks with fine-grained whitish specks (CRMP-393, 446AB). The outcrops appear jointed.

3.6.3 Stratigraphic relationships

They are found conformably over the Dudas basalts. In turn, these rocks are found below the Yunguilla Formation, which can be observed about 300 m upstream from point 551-129.

3.7 Dudas basalts

3.7.1 Location

They are located near the town of Taday at point 574-080.

3.7.2 Lithology

It is a light grey, aphanitic, massive rock; it is found in localized fractured outcrops, but without foliation (CRMP-394).

3.7.3 Stratigraphic relationships

At the moment, their stratigraphic relationships are unknown.



4. STRUCTURAL GEOLOGY

4.1 Folds

Folds were identified in an outcrop of the Yunguilla Formation, in the vicinity of Hacienda San Juan (541-074, Photo 4), with an axial plane at 177/84E and a fold axis at 190→20N extending toward the north, and is probably correlatable with the structures of the Yunguilla Formation found in the Asunción Dudas area.

Regarding the other lithological units, the degree of folding is so intense that its isoclinal character becomes confused with the foliation and its identification is very difficult, such is the case of the Alao-Paute division.

In other cases, it turns out that the rock is highly jointed, in patterns of diverse orientation.

4.2 Foliations

From the structural data taken, the foliations in general present very variable orientations and dips; however, from the few data points taken, a NE-SW trend in orientation is envisioned; the dip, for its part, is sometimes toward the N and sometimes toward the S. In the geological map (annex 1), what has been mentioned can be observed.

4.3 Joints

In addition to the foliations, measurements of joints were also carried out, the list of which is presented in annex 2, which includes the number of the corresponding station and is presented on the geological map.

Regarding the joints, several orientations can be defined, which have been represented in the point diagram included in the text, where the NW-SE orientation is predominant.

4.4 Geological faults

It is considered that evidence of faulting is present throughout the region, which generated extensive zones of mylonitization, visible in the Alao-Paute division; therefore, it can be considered that the region was subject to a regional faulting system, with an approximate NE-SW orientation.

5. ECONOMIC GEOLOGY

The minerals described below correspond to hand samples and are therefore tentative names. Once the respective laboratory tests are performed, a more exact nomenclature will be available.

5.1 Graphite

In the Zarpán area (596-074), graphitic phyllites (CRMP-366).

Rocks with equal characteristics were also found at the Desincho site, at 616-096 (CRMP-436).

5.2 Magnesite

Near Tampanchi at point 619-083, in the form of a whitish powder, a product of serpentinite alteration.

5.3 Sulphides

In the bed of the Quebrada Tasqui (649-070), sulphides in the form of pyrite cubes (CRMP-389AB).

Near Llamacón, at point 629-026, the rock presents significant mineralization represented by pyrite cubes (CRMP-452ABC).

Near Yanguán Hill at point 608-121, significant mineralization in the form of cubic pyrite crystals, several mm in diameter.

Near the Desincho site (620-093), pyrrhotite(?) mineralization was found (CRMP-437-A).

In the Río Juval, at point 664-268, pyrrhotite(?) mineralization was found (CRMP-427-B).

5.4 Gold placers

In the Río Dudas, black sand was extracted with no gold results (CRMP-P-074).

In the Quebrada Asunción Dudas (558-128), in several attempts, very little black sand was obtained, with no gold indication (CRMP-P-075).

In the same river, at point 550-133, two pan tests were conducted with negative results for gold (CRMP-P-076).

At Yanguán Hill, pan sampling was carried out; in two attempts, only a little black sand and a tiny speck of gold(?) were obtained (CRMP-P-077).

In the Río Juval, at point 671-260, in three attempts, a tiny speck of gold was extracted (CRMP-P-078).

In the Quebrada Dacñales, at point 626-035, in three pan washings, very little black sand was obtained with no sign of gold (CRMP-P-079).



In the Quebrada Juntas, at 610-012, very little black sand was found and there are no gold indications (CRMP-P-080).

In the Quebrada Tansaray, at 541-054, in four pan washings, plenty of black sand was obtained; however, no gold was detected (CRMP-P-081).

6. CONCLUSIONS AND RECOMMENDATIONS

According to the objectives of the commission, a preliminary and tentative conclusion was reached regarding the following delimitation of the “Tampanchi mafic-igneous complex”.

- (a) To the North: Left bank of the Río Pindilig, in the vicinity of the Desincho and Loma Ventanilla sites.
- (b) To the East: The Río Paute
- (c) To the South: Quebrada Dacñales
- (d) To the West: From the Desincho site, Tampanchi, upstream from the Quebrada Tasqui, the Huiñahuarta and Gafel hills

According to this preliminary delimitation, the approximate area in which this complex has been detected is approximately 18 km².

The rocks of the “Tampanchi mafic-igneous complex” are not found deformed as is the case with the Alao-Paute division; furthermore, they seem to correspond to a late stage of magmatism, for which, stratigraphically, the complex in question would be above the Alao-Paute division and, according to the data obtained, at least below the Tarqui Formation.

On the other hand, 20 km to the north, in the traverse carried out to the Río Juval valley (632-298), attention was paid to the possible presence of mafic rocks correlatable to those of the Tampanchi complex; at least in the investigated region, between points 640-286 and 676-249, no evidence of any kind was detected regarding the “Tampanchi mafic-igneous complex”, which tends to undermine the idea of its possible presence in an elongated N-S strip.

It is therefore recommended to carry out localized studies in the area, aimed at defining more precisely the limits and contacts of the complex in question. Specifically, to investigate the southern sector of the Chimborazo (585-53), Huiñahuarta (605-058), Nuñurca (570-041) hills and Salel Hill (600-042).

Regarding another of the objectives set for the commission, it is concluded that there are characteristic differences between the Yunguilla Formation and the Alao-Paute division; thus, while the Alao-Paute division is highly sheared, with at least two tectonic cleavages (S1 and S2) and various deformations (at least D1 and D2), the Yunguilla Formation has apparently suffered only one deformation (D1) and one stage of tectonic cleavage (S1); therefore, its rocks do not exhibit the degree of shearing present in the Alao-Paute division.

For this reason, it is logical to assume that the Alao-Paute division was formed first and underwent several stages of deformation and shearing; subsequently, the Yunguilla Formation originated, and then both lithological units underwent the final stage of deformation together. As a corollary of this, it follows that the Yunguilla Formation overlies the Alao-Paute division.

New outcrops tend to establish that the contact of the Yunguilla Formation is located further to the east, at least in the stretch between Quebrada de Mangán (513-056) and Asunción Dudas (554-125), in relation to the transitional dotted line placed on the “Cañar” geological map, scale 1:100000, DGGM, 1972-1973.

In this regard, it is recommended to carry out more thorough investigations aimed at defining more precisely the contact between the lithological units in question. Specifically, in the stretch between Quebrada de Mangán, Asunción Dudas and, further north, in the vicinity of Cerro Pilishurco (556-172).

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8. ANNEXES

8.1 Maps

- Stations
- Sample locations
- Geological

8.2 Structural data

List of structural joint data, point diagram, and frequency diagram.

8.3 Photos

- (1) View from Caballo Pugllana hill toward the Tampanchi area (625-081); the Río Pindilig valley is visible.
- (2) Fallen block with pseudo(?)cumulate structures, found in the Quebrada de Tasqui (640-071).
- (3) Iglesias site (615-064), Quebrada de Tasqui, outcrop with pseudo(?)cumulate structure.
- (4) Outcrop of the Yunguilla Formation in an eroded antiform, on the left bank of the Río Ramada. The outcropping blocks to the left of the road correspond to the Alao-Paute division; it is unknown whether or not they are in situ.
- (5) In the foreground, Loma Joaquín (538-098), on whose right bank rocks of the Yunguilla Formation outcrop and on the left bank the Alao-Paute division. In the background, to the left, Picotapata hill, where the geomorphology changes and there is significant evidence of Alao-Paute division rocks.
- (6) Breccia with constituent blocks of the Yunguilla Formation.

Ing. Miguel Pozo T.
CORDILLERA REAL PROJECT

No. 6912

QUITO, OCTOBER 28, 1988

TO : GERENTE TÉCNICO

FROM : ING. FRANCISCO VITERI and DR. JOHN ASPDEN

SUBJECT : Technical Report of the commission carried out from August 31 to September 25, 1988, in the south of the country.

1. INTRODUCTION

1.1 Project context

The Cordillera Real Project is carrying out a compilation of basic field information, both geological and structural at a regional level. Currently, it features an original geological configuration of the country, specifically within the Cordillera Real, in order to use these models to relate it to sectors of economic mineral concentration in different parts of the country.

1.2 Objectives

The main objectives of this commission, carried out from August 31 to September 25 of the current year, were to compile structural geological information in the southwest of the country, in the sectors of the Las Aradas Fault. This was performed in two stages of traverses; the first from Jimbura following the Río Isimanchi to Zumba, and from Amaluza, Manguira to Palanda.

In the second stage of this commission, a study was conducted in the sectors of La Canela, El Vergel, and the Río Panguri; finally, a reconnaissance was carried out through Malacatos, Filo Toledo, and El Tambo, in the province of Loja.



1.3 Assigned personnel

The following participated in this commission:

Ing. Francisco Viteri	INEMIN
Dr. John Aspden	ODA-BGS
Sr. Manuel Céleri	INEMIN
Sr. Germán Galeas	INEMIN

Using the British Mission's Land Rover vehicle, license plate AT-0056, for transport.

1.4 Hydrography

At a regional level in the area, the main drainage networks that dominate the western part are the Espíndola and Pindo rivers; the first serves as a boundary between Ecuador and Peru. These continue their drainage westward to form the Río Macará and discharge into the Pacific under the name of the Chira River in Peru.

In the drainage basin of the Oriente (Amazon) within the work area, the main drainages are the Río Isimanchi, Río Jíbaro, and Vergel. These drain toward the Río Numbala, which flows in a North-South direction, with the waters continuing toward the Río Zamora to later take the name of the Río Santiago and discharge into the Atlantic Ocean.

1.5 Climate and vegetation

The climate in the western sector of the study area, specifically around Amaluza and Jimbura, consists of temperate climate zones. The vegetation is varied; rice, sugar cane, cassava, etc., are cultivated. The route then moves to the high zones of the Cordillera de Sabanilla, with an altitude of up to 3600 mamsl, where the climate is cold and vegetation is low with small scrublands and grasslands (pajonales); winds are strong during the summer season. Finally, the route descends to the eastern zone, which is where the towns of Palanda, Valladolid, and Zumba are primarily located.

In these sectors, the climate is hot and humid at different times of the year, varying to temperate, where the vegetation is typical of eastern sectors, dominated by plantations of sugar cane, cassava, etc. The second zone where work was carried out has a hot humid climate with varying altitudes: Palanda 1187 mamsl, Cordillera de Numbala 2117 mamsl, Cumandá 1405 mamsl. The predominant vegetation is coffee and sugar cane; livestock is also of great importance.

1.6 Access

To the western part of the study area, access can be made from Loja, Amaluza, and Jimbura on second-class roads; however, from this point, the traverse toward the Oriente begins on foot to reach Palanda and La Diversión, respectively. From these points, there is a second-class road to exit toward Zumba, Malacatos, and Loja; the second stage from Palanda to La Canela and the Río Panguri is done entirely on foot. See Map No. 1.

2. GEOLOGY

2.1 Introduction

The details of the geological observations made during the Amaluza-Palanda, Jimbura-Zumba, and La Canela traverses, including the location of rocks and collected geochemical samples, are indicated in Map No. 2. All identifications are macroscopic based on hand samples; at the moment, we do not have thin sections or geochemical analysis data. Consequently, the results of this technical report are provisional.

It should be taken into account that the geological traverses of the eastern part of Amaluza-Palanda and Jimbura-Zumba were carried out by the Project in 1986 (Manguira-Palanda and Quebrada Ahogado-La Diversión-Zumba). Therefore, these preliminary reports should be reviewed for further details.

The main lithological divisions are indicated in Map No. 2 and are: the semipelitic division of Loja, the Sabanilla Complex, and the Tres Lagunas Suite. These divisions have been established by the Project previously (see Annual Report of the Cordillera Real Project 1987-1988).

2.2 Jimbura-Zumba and Amaluza-Palanda Traverse

In the first part of the performed traverse, namely Amaluza-Palanda and Jimbura-Zumba, it has been convenient to divide the geology into three zones: the western zone, the central zone corresponding to the Portachuela Batholith, and the eastern zone.

2.2.1 Western Zone

This corresponds to the area west of the Portachuela Batholith. In the southern part of Ecuador, the metamorphic rocks of the Cordillera Real are covered by a large extension of Lower Tertiary (Palaeocene) volcanic rocks belonging to the Sacapalca Formation (Baldock, 1982). Metamorphic rocks could only be seen south of Jimbura and in few places. The first outcrops occur approximately 4 km south of the Bermejo River and consist of a highly weathered biotite gneiss, which can be assigned to the Tres Lagunas Suite. Further southeast, these outcrops were perhaps replaced by mylonites, which have probably been silicified by the intrusion of the Portachuela Batholith. The outcrops of "metamorphic" rocks are discontinuous, but it is important to note that there is no evidence of much deformation in the Sacapalca Formation along the Portachuela Batholith.

The quality of the metamorphic rock exposures has prevented detailing existing local structures, but in regional terms, the Las Aradas fault defines the western structural limit of the Cordillera Real in southern Ecuador (see chapter "Geological reconnaissance of the Las Aradas fault", attached to this report). The presence of biotite gneiss of the Tres Lagunas Suite at the western limit of the Portachuela Batholith and the probable existence of mylonites have been considered to make an approximate trace of this fault. However, verification of SAR or SPOT images, which are not available in INEMIN, may demonstrate the position of the Las Aradas fault with greater accuracy.



2.2.2 Central Zone

The Central zone corresponds to the Portachuela Batholith, which is a major I-type intrusion composed of granite/granodiorite and diorite. These variations in the composition of the batholith are well-marked along the route south of Jimbura, and in the west, it consists of a leucocratic monzonite with hornblende and significant biotite, medium to coarse-grained. This sequence of rocks predominates to the north of this zone, specifically in the sectors of the Cachiragua and Yacuri lagoons; toward the east in the Laguna Silvan sector, this series is interrupted by porphyritic rocks mineralized with sulphides (pyrite and possibly gold). The same occurs in the outcrops exposed on the new road east of Quebrada Calderon (see Map 2). A K-Ar (biotite) dating of one of these porphyries gives an age of 12 ± 1 Ma. Preliminary interpretations of these results suggest that K-Ar ages are not recommended; however, the Portachuela Batholith is probably of Miocene age. These two phases have been dated by the Project, giving K-Ar ages (biotite and hornblende) that fluctuate from 24 ± 5 to 17 ± 1 Ma.

Although the western contact of the batholith is not very well exposed, in the southeast of San Andrés, it can be seen that the batholith intruded the older basement rocks of the Sabanilla Complex. We can also observe in the west of Las Juntas and San Andrés that there is a significant number of large blocks of higher-grade metamorphic rocks of the Sabanilla type, which have been considered as xenoliths and in some cases have the appearance of rafts (strips?) probably 1 km in size within the batholith.

Blocks of this type exist toward the west of the Río Esmeralda and have been seen frequently along the road from this river to Q. Troya. Based on their presence, these rocks are inferred in the southern part of the Cordillera; the width of the Sabanilla complex increases substantially, and there is a considerable decrease in the width of the Loja semipelitic division. Consequently, it is possible that in northern Peru, the metamorphic rocks of the Cordillera Real are similar to the equivalents of the Sabanilla Basement Complex.

2.2.3 Eastern Zone

In the south of the Eastern zone, the outcrops consist basically of medium to high-grade rocks of the Sabanilla Basement Complex, but toward the northwest of Manguira, there is a belt 4-5 km thick of low-grade rocks consisting of phyllites, metapelites, and quartzites, which belong to the Loja semipelitic division.

As we mentioned above, these latter rocks disappear toward the south. The contact between the Loja division and the Sabanilla Basement has not been observed due to the lack of outcrops in the north, but photogeological observations indicate that it may be a faulted contact.

In both traverses (Jimbura-Zumba and Amaluza-Palanda), the Sabanilla Basement Complex is poorly exposed and has not been studied in detail. As we can see in previous reports, this unit has a complex geological history; its lithology is composed of migmatites, biotite $\pm$ muscovite gneiss, banded; small quartzose schists and gneiss, with the presence of garnet being common.

Continuing with the traverse from San Andrés to La Diversión, the existence of fresh outcrops crossing the Sabanilla Basement is probable, which will be very interesting to study in the future.

2.2.4 Economic Geology

Analysis of samples collected on this traverse possibly shows no mineral indication of economic value. However, some areas may be of interest:

- (a) In the north of the Portachuela Batholith, porphyritic rock series with considerable amounts of sulphides, especially pyrite, are associated over a good extent. These are seen on the surface, and according to these geological characteristics, the gold being worked in the lower course of the Jimbura River is of great importance; these rocks with the same characteristics continue toward the south (Jimbura-Zumba section).
- (b) The existence of minerals, especially gold, in the Quebrada Ahogado to the east of San Andrés is possibly related to the fracture zones of the Portachuela Batholith.
- (c) According to reports from settlers, gold exists in the Río Isimanchi near San Andrés, but this area has not been confirmed by the present study.
- (d) Within the Portachuela Batholith, about 1 km west of the junction of Quebrada Las Coloradas with the Río Isimanchi, on the new road from Jimbura to San Andrés, there is a good exposure of a mineralized zone (mainly with sulphides and copper patinas).

2.3 Río Isimanchi-Mayo River Traverse

2.3.1 Introduction

Fieldwork was carried out along the Río Isimanchi to the Mayo River with the objective of determining the nature of the contact between the Mayo River Batholith and the oldest metasedimentary division of the Sub-Andean front (see Annual Report of the Cordillera Real Project, 1987-1988, Map 10).

2.3.2 Geology

The rocks corresponding to the oldest informal metasedimentary sequence are exposed along the lower part of the Río Isimanchi east of Zumba (see Map No. 2). Detailed petrographic studies of these rocks have not yet been performed, but this sequence, which includes massive limestones, is dominated by low-grade rocks such as green phyllites and quartzose phyllites, which substantially contain a good portion of volcanic rock detritus.



This sequence extends toward the north and we can see outcrops to the east of Valladolid along the bridle path that leads to Porvenir (see Annual Report of the Cordillera Real Project, 1987-1988, Map 10). They are also present to the east of Palanda.

Originally, we suggested that the Río Mayo Batholith intrudes this sequence and that it is now confined, with xenoliths of the oldest metasedimentary division existing within the marginal zone of the undeformed batholith (see Map No. 2).

However, some dating studies carried out abroad on the Río Mayo Batholith, with samples taken south of Palanda, have yielded K-Ar ages (hornblende/biotite) of 170-180 Ma. We conclude that a minimum age of Lower Jurassic would correspond to the metamorphic rocks of the oldest metasedimentary division.

It is confirmed that the metamorphic rocks are older in the Sub-Andean zone, due to the presence of large xenoliths of metamorphic rocks in the marginal zone of the Río Mayo Batholith (see Map No. 2).

These rocks are provisionally considered to be genetically related to the serpentinites and olivine microgabbros of the outcrops exposed very close to the east of Zumba, on the road toward Palanda; if this interpretation is correct, then our previous suggestions that these ultramafic rocks were related to an opening that occurred in the Lower Tertiary are not valid.

2.4 Geological reconnaissance of the Las Aradas fault

A fast reconnaissance was carried out along the Las Aradas fault, between the towns of Quilanga and Las Aradas, as well as in the south at the Río Airo and to the east of the hamlets of El Laurel and Granadillo (see Map No. 3).

In previous visits north of Quilanga and Loma del Inca, the presence of outcrops of semipelitic rocks of the Loja division was predominant, and the Tres Lagunas Suite was observed in smaller quantities (see Annual Report of the Cordillera Real Project, 1987-1988).

However, along the road leading north of Quilanga, there is an outcrop of greenschists, which is very similar to the Alao-Paute division (see Annual Report of the Cordillera Real Project, 1987-1988).

During this field commission, more outcrops of Alao-Paute were found south of Quilanga, along a second-order (unpaved) road leading to Las Aradas (see Map No. 4).

In another study sector and north of Quebrada El Saco, the presence of green rocks (meta-andesites) and their cataclastic products such as greenschists and phyllonites can be seen.



Furthermore, they are present as thrust-shaped lenses of a small scale (1 meter) which indicate tectonic transport from the SW to the NE. Lithologically, these rocks are identical to those of the Alao-Paute division, which have been seen along the Baños front south of Sigsig (see Annual Report of the Cordillera Real Project, 1987-1988), and their existence further confirms that the Las Aradas fault represents the southern extension of the Baños front.

In Quebrada El Saco, there is an exposure of mylonites with a strong westward dip, and these are considered as belonging to the Alao-Paute division. In the boulders of Quebrada El Saco, a predominance of gneissic blocks from the Tres Lagunas Suite can be seen, but it also includes semipelites from the Loja division; further south in Quebrada La Quiroga, there is a recognizable outcrop of the Alao-Paute division.

Further south, mylonites are exposed in the Río Airo and have strong westward dips; likewise, in Quebrada El Saco, there is a good proportion of boulders from the Tres Lagunas Suite. These boulders are also characteristic in Quebrada El Limo toward the south of Granadillo.

In other sites of this area, along the side of the road, there are some exposures of semipelitic rocks of the Loja division, but these are frequently covered by undeformed volcanic and volcano-sedimentary rocks, which, according to published geological maps, correspond to the Sacapalca Formation of Lower Tertiary age.

However, our work should be considered preliminary; we have not seen evidence of deformations in the Sacapalca Formation near the Las Aradas fault, which would allow us to suggest that the main movements along this fault are pre-Tertiary in age.

It is prudent to indicate that the approximate trace of the Las Aradas fault is designed according to our field observations, which are indicated on Map No. 3.

A study of satellite and/or radar images of this area could be conducted to locate the fault with greater precision, but unfortunately, these images do not exist in the INEMIN archives.



2.5 Palanda-La Canela geological traverse

The geology of this traverse can be divided into the following units (see Map No. 4).

2.5.1 Metamorphic rocks (pre-Jurassic)

This sequence of metamorphic rocks belongs to the oldest metasedimentary division of the Sub-Andean belt (see Annual Report of the Cordillera Real Project, 1987-1988); these are exposed along the bridle path that leads to Cumandá, located east of the Río Numbala. These rocks are considered as large strips (“rafts”) within the Río Mayo Batholith and consist of quartzose metasediments; in some cases, they are green when weathered, but in others, they are grey and black when the rock is fresh. These are low-grade and impure rocks.

There is evidence of at least two phases of deformation, which can be seen in outcrops and in chevron folds. Quartz veinlets are also common, and in some sectors, these rocks are exceptionally rich in psilomelane.

2.5.2 Santiago Formation (Lower Jurassic)

In a narrow strip of the Río Vergel with a north-south strike, sediments with westward dips are exposed. The outcrops in the northern part consist of micaceous sandstones, mauve-coloured, poorly sorted, and massive with ripple marks.

Above this location, an interbedded sequence of medium-grained sandstones of pale colour and argillites appears. The argillites are dark grey and carbonaceous. Internal fault slickensides are common and the entire sequence shows bioturbation.

The sandstones and argillites are relatively hard, and the base of the sandstone units frequently contains argillite flakes, which are present in approximately equal proportions, and individual layers are typically less than a meter thick.

Upstream (in the upper sequence), the sandstones disappear rapidly, and there are horizons of pale grey and fossiliferous limestones; pale calcareous argillites are also present.

However, most of the outcrops consist of finely laminated argillites and shales, rich in organic material and dark brown in colour. Boulders are common; the black argillites contain ammonites. These typically have a strong hydrocarbon odour when the rocks are struck with a hammer.

The age of these sediments is unknown, but field relationships suggest they are intruded by the Río Mayo Batholith; consequently, we have assigned this sequence to the Santiago Formation of Lower Jurassic age.

2.5.3 Río Mayo batholith (Jurassic)

Intrusive rocks of the Río Mayo Batholith extend from Palanda in the west toward the banks of the Vergel and Panguri rivers in the east.

This batholith has not been mapped in detail, but a variation in its composition can be observed. In general, between Cumandá and La Canela in the east, it consists of a medium-grained biotite and hornblende granodiorite, which is dominant in the study area; however, in the west, it is common to find a composition of hornblende and biotite monzonites, or quartz diorites.

In mapped sectors, the batholith also includes minor intrusives (e.g., felsite, andesite, and porphyry dikes).

Samples of the hornblende and biotite monzonite and quartz diorites were taken toward the south of Palanda, which have been dated (see Phase I of the Geochronology Report) and have a K-Ar age range (hornblende and biotite) of 186 ± 4 to 175 ± 14 Ma.

2.5.4 Volcanic rocks (Upper Jurassic-Lower Cretaceous)

In the Vergel and Panguri rivers, volcanic rocks are predominantly exposed. These rocks have not been dated, but they are assumed to be equivalents of the Upper Jurassic-Lower Cretaceous, corresponding to the Upper "Member" of the Chapiza Formation, namely Misahuallí.

In the Río Vergel, the outcrops consist of weathered andesitic agglomerates and lavas; the contact between these rocks and the Río Mayo batholith must be sought in order to establish a relationship.

In the lower parts of the Río Panguri, there are outcrops mainly of significantly weathered andesitic agglomerates and andesites, which are porphyritic rocks with feldspar. In Quebrada La Cerveza, there are agglomerates with considerable mineralization; it was also not possible to establish and locate a contact between these rocks and the intrusives due to the thick vegetation, as the outcrops are covered.

2.5.5 Hollín Formation (Aptian-Albian)

This Formation was observed in outcrops, but the existence of numerous blocks of medium-grained, friable, white sandstones is of importance; these were seen in the Río Vergel and in Quebrada La Cerveza, which is a northern tributary of the Río Panguri.

Furthermore, there are small areas of white sandstone with quartz along the bridle path that leads through the upper part of the Río Vergel toward the west of Santa Clara.

The same occurs approximately 2 or 3 km west of La Canela with the existence of white sand with quartz on the trail leading to Quebrada La Cerveza.



Toward the southeast of Chito (see Annual Report of the Cordillera Real Project, 1987-1988), the sandstones of the Hollín Formation rest unconformably on the Chapiza Formation (Misahuallí Member), and we assume that it is the same relationship existing in the area. However, it should be noted that the limits of the Hollín Formation outcrops, as indicated on Map No. 4, were designed based on photogeology.

2.5.6 Economic Geology

The Hollín Formation is of potential importance for glass manufacturing, this being the main significant non-metallic mineral in the study area. Creeks and rivers have been panned along the Vergel and Panguri rivers, with a higher gold content found in pans in the Río Panguri and most of its tributary creeks.

In the upper part of the Río Vergel, a recently discovered mine for the exploitation of gold in rock appears. This area (see Map No. 4, AU?) was visited by Project personnel, but unfortunately “La Cooperativa?” prevented us from visiting the worksite.

The interpretation of this area, as shown on Map No. 4, is based on photogeological data, and we assume that the mineralization is associated with the volcanic rocks of the Misahuallí Member of the Chapiza Formation.

Ing. Francisco Viteri

Dr. John Aspden

CORDILLERA REAL PROJECT

No. 0001

QUITO, JANUARY 02, 1989

TO : GERENTE TÉCNICO

FROM : ING. FRANCISCO VITERI and DR. JOHN ASPDEN

SUBJECT : Technical Report of the commission carried out from November 01 to 25, 1988, in the southeastern part of the country (Numbala, San Vicente, Yacuambí).

1. INTRODUCTION

1.1 Project context

The Geological Research Project of the Cordillera Real, which is being carried out through a Technical Assistance agreement between the governments of Ecuador and Great Britain, involves the collection of field data at a regional scale. This work aims to establish a model of its formation processes and use this data to correlate them with existing mineral concentration sectors in different parts of the country, particularly in the Cordillera Real.

1.2 Objectives

The basic objectives of this commission were to compile geological-structural information in the south of the country, primarily in the sectors of the Río Numbala, Espíritu Playa, Nabón, Shingata, Tutupali, San Vicente, Yacuambí, La Paz, and Fierro Urco. Additionally, the mission sought to take petrographic and geochemical samples of fluvial sediments and heavy minerals at sites of interest to relate them to regional geological models deduced in previous commissions.

1.3 Assigned personnel

The present commission was composed of:

Ing. Francisco Viteri	INEMIN
Dr. John Aspden	ODA
Sr. Manuel Céleri	Driller/INEMIN
Sr. Washington Cevallos	Driver/INEMIN

A Land Rover Jeep AT-0056 from the British Mission was used as the means of transport.



1.4 Hydrography

In the study area at a regional level (see Map No. 1), the dominant drainage networks are the Yacuambí, Zamora, and Numbala rivers. All of these drain into the Zamora, then take the name Marañón, and eventually discharge into the Amazon under the name Santiago. The Leon and Oña rivers form another important network; these drain toward the west to eventually reach the Jubones River on the Ecuadorian coast.

1.5 Climate and vegetation

Within the entire research area, climates are variable. In the high parts above 3000 mamsl, there are cold páramo climates with low vegetation, where few crops of potatoes and beans exist. In higher sites, frosts predominate, especially in Loma Picota, La Cruz, and Shingata. Another type of climate is found in the Sub-Andean (Eastern) region with altitudes below 2000 mamsl, where the climate is hot and humid, and the vegetation is abundant and varied, including cane and cassava, among others. Within these zones, the towns of Yacuambí, Espíritu Playa, La Paz, and small hamlets are located.

1.6 Access

To carry out the geological-structural study, the city of Loja and the new canton of Nabón, in the province of Azuay, served as the main operations centres.

The first stage of the commission took place in the Upper and Lower Numbala sectors (see Map No. 3). To reach these points, a primary road is taken from Loja to Yangana, followed by a paved road to Pico Toledo, starting the traverse on foot to Numbala from that point.

The second phase was carried out through the Nabón-Cochapata sectors to near Shingata via paved roads, then taking a bridle path to Tutupali and Yacuambí. The second group conducted the traverse on foot from La Cruz to Espíritu Playa (see Map 2). Other geological studies (see Maps 4 and 5) were conducted via secondary roads.

2. GEOLOGY

Details of the geological observations, mostly carried out on foot via bridle paths, trails, and creeks, can be observed on the Cochapata-Yacuambí and Nabón-Espíritu Playa maps (See Map No. 2); Pico Toledo-Numbala (see Map No. 3); and via paved roads Loja-Cera and San Lucas-Fierro Urco on Maps 4 and 5, respectively. It should be noted that all identifications are macroscopic based on hand samples, as thin sections were not available at the time, nor were the geochemistry results. Consequently, all interpretations made on the geological maps attached to this technical report are provisional.



2.1 Geological traverse Cochapata-Yacuambí and Nabón-La Cruz-Espíritu Playa

The geological information obtained from Nabón-Espíritu Playa was carried out by Ing. Francisco Viteri and that of Cochapata-San Vicente-Tutupali by Dr. John Aspden; these two traverses are shown on Map No. 2. To the west, a large expanse of volcanic deposits of the Tarqui Formation can be observed, which covers much of the mountain range in the form of a sheet, but on the eastern side the metamorphic rocks can, in one way or another, be clearly assigned to the Tres Lagunas Unit or the Loja semipelitic division. Additionally, in the north, a thin belt of metalavas is exposed, which belong to the Alao-Paute division immediately or very close to the west of the Tres Lagunas Unit.

2.1.1 Alao-Paute division

Outcrops of these rocks are very restricted toward the northwestern part of the map and consist mainly of greenschists. Structural data indicate moderately strong dips toward the west.

Lithologically, these rocks are very similar to those we have seen in various sectors in the Alao-Paute division, and their presence provides us with an important link to the main outcrops of the Alao-Paute division to the east of Cuenca and those recently described by the Project in the Quilanga area to the south.

The current contact between the Alao-Paute division and the Tres Lagunas Batholith is not very well exposed; however, it is indicated on Map No. 2, which was taken from the southern extension of the Baños front.

2.1.2 Tres Lagunas batholith

The Tres Lagunas Unit was named thanks to the field results carried out by the Southern Brigade (Aspden, Viteri, 1987) of the Cordillera Real Project (see Oña-Yacuambí geological traverse, August 1987), a place where many outcrops of deformed biotitic granite were found. Based on field observations made during the two traverses indicated on Map No. 2 attached to this technical report, it is possible that these same rocks extend toward the north and probably represent a single intrusion; despite the intrusive being strongly deformed, perhaps the Tres Lagunas Batholith represents a single body.

The western margin of the Tres Lagunas Batholith is mostly covered by felsic, Plio-Pleistocene tuffs of the Tarqui Formation, and the contact is indicated on Map No. 2, which is based on photogeological interpretations. The eastern contact of the intrusions can be assumed to be intrusive, but for this, it is necessary to verify with detailed field checks.



Lithologically, the batholith consists of a biotitic granite with a granular and coarse texture, generally gneissic, but with variable deformation. There is a variety with blue-grey feldspar megacrysts which give the form of very common “augen” (eyes) gneiss. At times, the granite also contains blue quartz, which could be associated with microshearing specifically developed within the quartz grains. In the north, there are blocks of muscovitic gneiss with a “greisen appearance” in the Espíritu Playa or Río Yerbabuena (see technical report Gima-Nueva Tarqui, February 1988). There are outcrops of altered granite (indicating muscovite) to the west of the Río Moriré, along the eastern margin of the longer, non-deformed Tertiary batholith (hornblende ± biotite granodiorite), which is shown on Map No. 2.

In the Río Macuchi, irregular pegmatite veinlets with tourmaline were observed in boulders of the Tres Lagunas Granite; also in this same river, there are numerous large blocks of white quartz up to 50 cm, some of which carry pegmatitic tourmaline in the form of irregular crystals.

In the west, structural dips are moderate to strongly inclined toward the west; however, in the eastern part of the batholith, they are toward the east, while the strikes are markedly trans-cordillera.

2.1.3 Loja division

To the east of the Tres Lagunas batholith, we have the Loja division, which consists of a monotonous sequence of low-grade rocks, mainly phyllites ± graphite, siltstones, and medium-to-fine-grained quartzite. On a smaller scale, secondary folds (F₂) can be seen, which generally have gentle dips. The fold axes have a cordillera strike and are very common.

2.1.4 Young intrusive rocks

Toward the eastern margin of the Tres Lagunas batholith, minor late intrusions are present, without deformation. In the north, they consist of granodiorites with hornblende ± biotite, and in the south, basic diorites (gabbros?) are predominant.

The age of the plutons is unknown, but they possibly have a lower Tertiary age.

2.2 Economic Geology

2.2.1 Gold

Alluvial gold was obtained as a result of panning in some rivers and creeks, which are indicated on Map No. 2.

In the west of the Shingata and Betas rivers, at the southern limit of the gold belt (Collay-Shingata) which is associated with the Baños front, auriferous mineralization could be observed.

As mentioned in previous works carried out in the Cordillera Real, the origin of the gold in this auriferous belt has not yet been identified; therefore, it is recommended to conduct detailed field work, which should be performed in the Quebrada Macuchi (see Map No. 2). This creek is relatively short with no access problems and has been worked by local miners; based on our observations, which were carried out in the lower course of the creek, there could be good outcrops upstream and potentially the opportunity to find primary gold on the surface. For this purpose, a detailed geological-research study should be conducted with the objective of identifying the primary sources of gold in this creek and along the Collay-Shingata auriferous belt.

In the east, around San Vicente, some rivers carry alluvial gold; the origin of this gold is unknown, although it may possibly derive from quartz veinlets existing in the semipelitic rocks of the Loja division.

Some rivers and creeks carry boulders of young volcanic and intrusive rocks, which have been draining from the Sub-Andean volcanic/plutonic belt, and in some places, these rocks are associated with the regional extension of auriferous mineralization in the southern part of Ecuador (Sub-Andean belt gold belt).

In the surroundings of the town known as Espíritu Playa, northwest of San Miguel de Cuyes, the existing alteration in the intrusive rocks of the Tres Lagunas Unit is important, possibly due to the effect of the young intrusive (described in the previous chapter), which contains a large number of sulphides such as pyrite, chalcopyrite, and bornite in some cases. As a result of the panning carried out in the Quebrada Yerbabuena and its tributaries of Espíritu Playa, the existence of alluvial gold was confirmed, so it would be advisable to carry out a detailed geological-geochemical program within this zone with the purpose of determining the primary source of auriferous mineralization.

2.2.2 Tin and tungsten

The Tres Lagunas Batholith is considered an S-type granite, and consequently, there is the possibility that it may be partially associated with tin and tungsten mineralization. In the Quebrada Macuchi, it is common to find granite blocks with irregular veinlets, sometimes filled with quartz and pegmatitic tourmaline.

Heavy mineral samples have been taken for laboratory analysis for Sn and W. Similar samples were collected from the Espíritu Playa and Yerbabuena rivers.

2.3 Pico Toledo-Numbala geological traverse

The objective of this expedition was to verify the existence of the contact between the Sabanilla Basement rocks and the oldest metasedimentary rocks of the Sub-Andean belt, as well as to observe the presence of mineral occurrences within the study area.



In previous works carried out by the Project (see Loja-Zumba report, November 1986), a geological reconnaissance was conducted from Yangana to Pico Toledo, finding the contact between semipelitic rocks of the Loja division and the Sabanilla Basement, approximately 10 km following the road from Yangana to Pico Toledo, without further additional information to the east; the need was seen to perform a geological investigation in Upper and Lower Numbala, with the objective previously described.

2.3.1 Geology

From Pico Toledo (3485 mamsl) where the traverse begins, there is a predominance of medium to high-grade rocks corresponding to the Sabanilla Basement Complex, mainly migmatites, pegmatites with garnet, and biotite gneiss. In higher sites, there is a predominance of amphibolites, in some cases in the form of dikes. The contact of these rocks with the volcanics located in the Río Numbala is situated in the Quebrada Perla (see Map No. 3), which is likely a tectonic (faulted) contact.

The main structure has an approximately north-south strike with dominant westward dips, with strong, almost vertical inclinations existing near the fault in most cases.

All along the Río Numbala and in the Quebrada Perla near the junction with the Numbala, there are good exposures of volcanic rocks (pyroclasts and lavas), highly silicified, likely corresponding to the Misahuallí Formation. These rocks contain a large number of sulphides; in hand samples, pyrite has been identified. Although these rocks have not been dated, we believe they are equivalents to the Upper Jurassic-Lower Cretaceous, corresponding to the Upper Member of the Chapiza Formation, that is, the Misahuallí Member.

In most of the exposed outcrops, the lithology consists of porphyritic rocks, felsites in the form of dikes, and lavas, all of which are highly silicified. Near the fault, there are rock alterations indicating epidote, chalcopyrite, and pyrite.

2.3.2 Economic Geology

According to the samples collected on this traverse, it has been observed that some of these contain indications of economic minerals, especially in the San Francisco Creek and in the Río Numbala where the outcrops of silicified volcanic rocks contain a good amount of sulphides. Panning samples were obtained from each of the rivers and creeks in this zone, with gold specks present in all of them, which would suggest that this is a recommended sector for conducting detailed geological studies and for searching for more mineral indications in this area. Another important sector is Quebrada Los Helechos near the junction with the Numbala, where gold washing operations exist. This mineralization may be associated with fracture zones of the Zamora Batholith, which is very close to the investigated area.

2.4 Geological traverse Loja-Cera and Loja-Santiago (new road)

In parallel with the regional geology work being carried out by the Project, detailed geological studies are being conducted with the purpose of confirming and correcting the currently existing geological model of the Cordillera Real in the southern part of the Project (see Map No. 10, Second Annual Report of the Cordillera Real Project); it is for this reason that the study was conducted in this zone.

2.4.1 Geology

The geology of the metamorphic rocks around the northern part of the contact of the Loja Tertiary basin has been checked in detail, and each of the geological-structural data points is indicated on Map No. 4. It should be noted that with the exception of the Loja-Solamar roads and the old Loja-Catamayo road, the positions of the other roads indicated on the map are approximate.

Previous studies carried out by the Project have demonstrated that along both roads (the new and old) connecting Loja with Catamayo, very good outcrops of low-grade rocks of the Loja semipelitic sequence are exposed. However, along the new road toward the west of the town of El Belén, and if we look toward the west of the margin of the Loja sedimentary basin, we can observe that a narrow faulted and banded block is exposed, indicating high-grade rocks, mainly quartz-biotite gneiss.

There are also very similar and particularly well-exposed rocks along the Loja-Solamar road (see Saraguro-Loja technical report, June 1986), along the new road between Loja and Santiago (San Lucas), and along the paved road leading to Taquil.

The relationship between the semipelitic rocks of the Loja division and the high-grade rocks - that is, the gneisses (and schists) - is unknown. The eastern flank of the gneisses, which are informally referred to here in this report as the Masaca gneissic division, may not have correct contact boundaries; in any case, it is tentative to suggest that this contact may correspond to a medium or strong photogeological lineament. The position of this lineament is indicated on Map No. 4; however, in the west, structural information and outcrop distribution suggest that the Masaca division is not structurally linked to the Loja division and could therefore represent an older basement sequence.

Lithologically, the Masaca division consists of biotite gneiss, rich in quartz; in the east, there is banded gneiss with biotite, and in the far west near the Las Aradas fault, gneissic schists and biotite-rich schists are common. Most of the observed rocks appear to be of the paragneiss type and consequently are not currently considered to belong to the Tres Lagunas Unit as we had previously suggested.

Near the Las Aradas fault in the areas of Taquil and Gauga, there are late muscovitic pegmatitic granite veins (without deformation) that cut the Masaca division; similar boulders exist in the Quebrada Solamar, which contain veinlets and concentrations of tourmaline.



While the wide distribution of the Loja semipelitic division and the Masaca division can possibly justify the information given in Map No. 4, detailed geological work should be scheduled in these areas with the objective of determining the structural relationship between these two divisions.

2.5 San Lucas-Fierro Urco geological section

Toward the north of San Lucas and along a paved road leading to Fierro Urco, outcrops of phyllites ± graphite are exposed toward the east.

This series of rocks may correspond to the same sequence of rocks as the outcrops existing along the main road that goes from Saraguro to San Lucas (see Saraguro-Loja report, Aspden-Viteri, June 1986), and toward the west, they are replaced by andesitic lavas of greenish coloration, which are relatively massive and weakly deformed, but which carry a widely exposed tectonic cleavage.

According to previous works (e.g., Baldock, 1982), these andesites correspond to the Celica Formation, and the metasediments have been tentatively assigned by various works carried out by the Cordillera Real Project as the Loja semipelitic division.

Additionally, toward the north along the new road to Saraguro, there are small outcrops of green volcanic rocks and greenschists, which are located to the east of the Honda Creek (see Map No. 5). In hand samples, these rocks are very similar to the metalavas of the Alao-Paute division, with which these outcrops have been related.

2.5.1 Recommendations

The observations described in this chapter have been made based on observations made in the field; however, any change may occur when thin sections are prepared. In particular, the relationship between the more massive andesites of the Celica Formation and the greenschists and green volcanics of the Alao-Paute division needs to be established, as well as the age of the metasedimentary rocks (we assume Loja division), which should be determined.

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